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HISTORY OF U. S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES (1920 TO 1970)

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Army Engineer Topographic Laboratories
Fort Belvoir, Virginia

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This document presents the historical development of the Engineer Topographic Laboratories from the period immediately following World War I to 1970. It includes a description of the major research and development programs of that period and listings in the Appendices of technical personnel responsible for these research and development programs as well as listings of technical reports published.

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FOREWORD

In the preparation of this history, the information for the period from post World War I through World War II was based largely on three unpublished volumes available in typed manuscript form and the personal involvement of the author in the later days of that period. These unpublished volumes were prepared by the Historical Staff of the Engineer Board at the close of World War II. For the period from World War II to the establishment of the U.S. Army Geodesy Intelligence and Mapping Agency (GIMRADA) in 1960, the historical information was based largely on consolidated, annual project reports of the U.S. Army Engineer Research and Development Laboratories (ERDL) which are available for most of the period. The author was also personally involved in the research and development activity throughout that period. For the period since the establishment of GIMRADA, the author relied primarily on historical summaries of the period's major programs, which were prepared by present Engineer Topographic Laboratories (ETL) personnel, supplemented by information contained in technical reports prepared during the period. Organizational and management information was obtained from the files of the Administrative Services Department of ETL and the old records retained in the management office of the Mobility Research and Development Command.

This history contains no information concerning classified research and development activity although significant classified programs were accomplished, particularly in the 1960 to 1970 period.

CONTENTS

Section	Title	Page

ILLUSTRATIONS

HISTORY OF THE U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES

I. INTRODUCTION

The U.S. Army Engineer Topographic Laboratories (ETL) is the principal field activity of the Army for research and development of topographic science equipment, procedures, and techniques. These include mapping, geodesy, and military geographic information. Work is assigned to the laboratories under research and development projects utilizing research, development, test and evaluation (RDTE) funds or other appropriate funds.

At the close of the period covered by this history, ETL's internal organization comprised a Research Institute, a Computer Sciences Laboratory, and five operating divisions: the Topographic Engineering Division, the Automated Mapping Division, the Photographic Interpretation Research Division, the Geographic Sciences Division, and the Surveying and Geodesy Division. The organization also included a field office at Wright-Patterson Air Force Base. The total staff was 7 military and 205 civilian personnel.

The U.S. Army Engineer Topographic Laboratories as a separate class II activity under the Chief of Engineers actually dates from 1 August 1960. At that time, the U.S. Army Engineer Geodesy, Intelligence and Mapping Research and Development Agency (GIMRADA) was established. (The name of the organization was changed to the U.S. Army Engineer Topographic Laboratories by General Order No. 13, Office of the Chief of Engineers, 31 July 1967.) However, the organization actually resulted from an evolution over the years beginning with a small research and development activity in the topographic field in pre-World War II days. A history of the organization would not be complete without reviewing these early beginnings and the work accomplished in the pioneering days. This period covers almost 50 years. It was an era in which surveying practice advanced from the transit and tape traverse and the invar steel tape for baseline measurement to the application of sophisticated electronic and optical distance-measuring devices and systems which, with the use of artificial earth satellites, permit precise geodetic measurements over long distances. The art of mapping has advanced from the plane table to automated and computer-controlled instrumentation for processing photographic and radar sensor information at high rates.

The development of mapping in the early days of this period through World War II is detailed in three unpublished volumes prepared by the Historical Staff of the Engineer Board at the close of World War II. These volumes are: MP-1, Photomapping, 17 July 1946; MP-2, Map Reproduction, 29 October 1946; and MP-3, Surveying and Navigation,

27 January 1947. For the period from World War II to the establishment of GIMRADA in 1960, the research and development activities are summarized in the consolidated annual project reports of the U. S. Army Engineer Research and Development Laboratories (ERDL), which are available for most of the period.

In addition to these source documents, the personal involvement of the author was heavily relied on for technical information concerning research and development activity through 1960. For the period 1960 to 1970, the present staff of ETL provided summaries of the major programs which served as a basis for the historical and technical information. Organization charts are located in Appendix A.

II. BACKGROUND

1. **Organization Through World War II.** In April 1920, Major James W. Bagley, Corps of Engineers, was assigned to cooperate with the Army Air Service in carrying out tests of aerial photographs for topographic mapping. Major Bagley invented the tri-lens camera used by the United States Army in World War I. His arrival at Dayton, Ohio, where the Air Service (which later became the U. S. Army Air Corps) had its largest testing facility, marked the origin of the Engineer Detachment which was destined to conduct most of the Corps of Engineers photogrammetric research until 1943.

The Detachment, which was originally called the Aerial Mapping Detachment and operated under funds provided by the Air Service, consisted until 1935 of one or two officers and from three to five enlisted men. Since the men were temporarily assigned from various engineer units, personnel turnovers were frequent. In October 1935, the War Department approved a permanent detachment of one master sergeant, one technical sergeant, one sergeant, and one corporal. Two officers and four civilians completed the roster. The limited research and development work in the surveying and map reproduction areas of the topographic field before the mid-1930's was assigned for the most part to the Engineer Board or its predecessor, the Board on Engineer Equipment, with headquarters at Fort Belvoir. The Army Map Service did additional research in the field both on its own initiative and at the request of other agencies.

By AR 100-30, *Engineer Board*, dated 26 January 1933, the Engineer Board was granted authority for technical supervision over the development of engineer equipment by the Engineer Detachment. In practice, however, the Detachment continued to operate autonomously under the same general directives as those received by the Board. After the Engineer Board began active photomapping work in 1933, a joint conference of representatives from the Office, Chief of Engineers, the Engineer Board, and the Detachment decided to coordinate the efforts of the two developing agencies by restricting the Detachment activities. From that time, the Detachment was to investigate only specific technical subjects recommended by the Engineer Board or the Detachment itself

and assigned by the Chief of Engineers. The Engineer Board was to consider the general doctrine of mapping, to suggest subjects for investigation, and to consider the technical reports prepared by the Detachment.

Following this conference, the Engineer Board's mapping work increased considerably. However, it was not until the Engineer Board reorganization of 30 June 1941 that the mapping section of the Board was raised to the status of a Branch. The Branch was placed in Technical Division I some time before 1 July 1942. Major Fredrick J. Dau was the first Branch Chief. He was succeeded by Captain William C. Cude on 1 July 1942.

A Research Section was established in the Reproduction Division of the Engineer Reproduction Plant (later the Army Map Service) in September 1940 to investigate new techniques and equipment for the duplication and printing of maps. The authority to exercise technical supervision over the development of engineer equipment by the Engineer Reproduction Plant was given to the Engineer Board by AR 100-30. However, this authority was not exercised in practice.

To take advantage of new facilities being built at Fort Belvoir in 1941 and to concentrate the research and development activity in the mapping field, the Engineer Detachment recommended in March 1941 that it be transferred to Fort Belvoir. It further recommended its replacement at Wright Field with a small detail to be known as the Aerial Photographic Branch of the Board. On 4 December 1942, this arrangement was approved with the provision that the Aerial Photographic Branch maintain liaison with the Air Force on mapping equipment of all types as well as on camera equipment.

Accordingly, on 19 February 1943, the Engineer Detachment terminated its independent existence and became a part of the Engineer Board. The Commanding Officer of the Detachment, Captain Gilbert G. Lorenz, remained at Dayton and became the first Chief of the Aerial Photographic Branch.

2. **Evolution of the Organization to 1960.** Approximately 1 April 1946, in a general reorganization of the Engineer Board, the Mapping Branch was elevated to the status of a Department and designated Technical Department V. At this time, the authorized number of personnel for mapping research and development was increased to about 50, although only 30 were on the staff. Four branches were established within the Department: the Ground Control Branch, the Photo and Lithographic Branch, the Photogrammetric Branch, and the Aerial Photographic Branch at Wright Field. The Photo and Lithographic Branch, in addition to its research and development program, provided technical photographic service for the entire Engineer Board.

This organization remained essentially intact through the early post-war years. The next change of any significance occurred in 1951 when Technical Department V was

redesignated the Topographic Engineering Department of ERDL. (The Engineer Board was redesignated ERDL in 1947.) At this time (1951), the Ground Control Branch was redesignated the Surveying Branch; the Photogrammetric Branch was redesignated the Map Compilation Branch with Cartography, Photogrammetry, and Map Compilation Techniques Sections; and the Photo and Lithographic Branch was redesignated the Map Reproduction Branch. The changes in the section alignment in the Map Compilation Branch were due in part to change in work emphasis. The change resulted from the expansion of the research and development responsibilities of the Chief of Engineers in the field of materials for cartographic drafting and reproduction to include responsibilities within the Department of Defense.*

In 1956, the Surveying Branch was reorganized and redesignated the Survey and Geodesy Branch. It included four sections: Electronic Survey, Air and Ground Techniques, Geodetic and Astronomic, and Application Engineering to better manage expanding research and development programs in these fields. At this time, development of Ground Survey Electronic Equipment by the Signal Corps (which had been assigned this task in 1947 on the recommendation of the Chief of Engineers) was terminated. Further development in this area was assumed by the Corps of Engineers. Up to this time, research activity of the Corps of Engineers in this area had been limited to the development of methods for using such equipment.

In addition, there was considerable activity in the mid-1950's in the application of airborne electronic equipment for long-range and geodetic surveying applications. This occurred because of advances in the state-of-the-art in these areas and requirements for more rapid and longer-range surveying techniques to provide position data for the newly developed long-range missiles.

The Map Compilation Branch was reorganized in 1956 when the Analytical and Automatic Mapping Section was set up in recognition of the increasing importance and expansion of programs in these areas. At this time, the Cartography Section was made a part of the Map Reproduction Branch. An Applications Engineering Section was added to each of the technical branches in 1957. These applications engineering sections were set up to manage development projects from the engineer test phase through service test and item classification in an effort to expedite these phases of item development projects.

The next significant change in organization occurred in 1959 when a Topographic Systems Branch was formed in recognition of the necessity for an overall system approach to the solution of topographic mapping problems and the need for more basic research for future and longer-range development programs. This branch was staffed by

*RDB Memo 244/2, subject: Assignment of Responsibility to the Department of the Army for Research in the Field of Materials for Cartographic Drafting and Reproduction, 3 January 1950.

personnel transferred from the Map Compilation Branch and the former Map Reproduction Branch. The Map Reproduction Branch became a section in the new Topographic Systems Branch. The branch also included a Systems Analysis Section which was charged with the responsibility for research studies on topographic mapping and position determination systems and the formulation and analysis of proposed systems. A Research Section was responsible for basic and applied research for new surveying, geodesy, mapping, position determination, cartographic drafting, and map reproduction principles and techniques. This actually marked the beginning of the development of the organizational concept separating basic research elements and programs from the development elements and programs. Later, in the 1960's this separation resulted in the formation of the Research Institute in the Engineer Topographic Laboratories.

By the end of 1959, the staff of the Topographic Engineering Department which was assigned to topographic research and development had approximately doubled as compared to the number of personnel at the close of World War II. The total research and development staff comprised 9 military and 98 civilian personnel. Technical personnel responsible for development through World War II are listed in Appendix B, and those responsible for the development from World War II to 1960 are listed in Appendix C. Technical reports on development are listed in Appendix D.

III. ESTABLISHMENT OF THE U. S. ARMY ENGINEER GEODESY, INTELLIGENCE AND MAPPING RESEARCH AND DEVELOPMENT AGENCY (GIMRADA)

3. **Rationale for GIMRADA.** By the end of 1959, there was ample evidence that the research and development activities would have to be greatly increased to fully meet Army research and development responsibilities in the technical field of mapping and geodesy. This expansion was the inevitable outgrowth of two technological advances which were creating a revolution in our ability to produce geodetic data and maps—the application of automation and digital computers in the compilation and the reduction of data; and the use of missiles and satellites as vehicles with which raw data could be obtained.

Army research and development activities in support of mapping and geodesy since World War II had been concentrated primarily upon combat mapping and survey systems and items and components for issue to Army tactical units. These requirements were still considered vitally important. However, the envolvement of the missile and satellite era, confirmation of Army world-wide military mapping and geodetic responsibility by the Department of Defense, and marked advances in the state-of-the-art for future geodetic and mapping operations, highlighted a need for greatly increased emphasis and major effort by the Army on global or strategic mapping and geodetic systems to provide

basic map coverage and geodetic control for common use by all elements of the Armed Forces.

4. **Authorization.** In recognition of the need for greatly increased emphasis and major effort in these areas and because a substantial research program and staff not properly coordinated with the ERDL program and staff, were being developed at the Army Map Service, the Chief of Engineers established the U. S. Army Engineer Geodesy, Intelligence and Mapping Research and Development Agency.[1] Effective 1 August 1960, it became a separate Class II activity under the direct command of the Chief of Engineers, with headquarters at Fort Belvoir, Virginia.

The order establishing the agency directed that all research and development effort and projects in the field of topographic engineering being performed at the time by the Topographic Engineering Department, ERDL, and all research and development effort in the fields of geodesy, intelligence, and mapping being performed at the time by the technical developments staff, Army Map Service, be assigned to the U. S. Army Engineer Geodesy Intelligence and Mapping Research and Development Agency. Further, the Commanding General, U. S. Army Engineer Center and Fort Belvoir, the Commanding Officer, ERDL, and the Commanding Officer, Army Map Service, were directed to perform the necessary administrative and support functions for the elements of GIMRADA at their respective stations. Colonel L. L. Haseman was designated the first Director of GIMRADA.

5. **Mission.** The mission statement for the newly designated agency was as follows:

"The U. S. Army Engineer Geodesy, Intelligence and Mapping Research and Development Agency (GIMRADA) is a Class II activity under the Chief of Engineers. It is the principal field agency of the Corps of Engineers for the accomplishment of research and development of equipment, procedures, and techniques in the specific fields of geodesy, engineer intelligence, and mapping for application both to troop and base-plant operation. The Chief of Engineers may assign work to this agency under research and development projects utilizing either RDT&E funds or other appropriate funds."

IV. ORGANIZATION AND FUNCTIONS

6. **Original Organization of GIMRADA.** The first published organization chart for GIMRADA is dated 1 May 1961. The Agency was organized into six operating divisions under a military director, a civilian assistant director, a civilian technical director, and a military executive officer. At the staff level and reporting to the directorate, the

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[1] General Order No. 22, Headquarters, Department of the Army, Office of the Chief of Engineers, 2 August 1960.

organization included a Systems Control Office, an AMS Liaison Office, and a USAF Liaison Office located at Wright-Patterson Air Force Base (the former Aerial Photographic Branch of the Topographic Engineering Department, ERDL). The USASRDL Liaison Office located at Fort Monmouth, New Jersey, was established to provide coordination between the Corps of Engineers and the Signal Corps—particularly the U. S. Army Signal Research and Development Agency and the U. S. Army Electronic Proving Ground at Fort Huachuca, Arizona. This office was responsible for coordination on matters of joint interest pertaining to geodesy, engineer intelligence, and mapping, including photographic and radar sensors being developed for Army aircraft and systems.

The AMS Liaison Office was never staffed. It was intended that the personnel of the Technical Development Staff of AMS be transferred to the new agency as were all of the personnel of the Topographic Engineering Department of ERDL. However, no transfer was ever effected, and the personnel were assimilated into various capacities in the AMS operation.

The six operating divisions of GIMRADA and their functional statements were as follows:

a. **Research and Analysis Division.** The Research and Analysis Division conducts basic and applied research in various scientific disciplines as required for new principles and techniques pertinent to surveying, geodesy, mapping, position determination, targeting, cartographic drafting, information display and dissemination, and map reproduction to meet both tactical and strategic requirements for geodetic and mapping data.

b. **Intelligence Division.** The Intelligence Division conducts research, development, design, and tests of new and improved methods, techniques, equipment, and systems in support of engineer combat and strategic intelligence in acquisition, processing, analysis, evaluation, presentation, dissemination, storage, retrieval, and updating of engineer intelligence data and information.

c. **Strategic Systems Division.** The Strategic Systems Division conducts applied research, development, design, and testing of topographic mapping systems involving aircraft, missile, or satellite-borne data acquisition and ground-based data reduction subsystems. The Division's responsibilities included feasibility studies and tests to establish system concepts and component requirements, system engineering, system investigation, and systems/components compatibility. In addition, the Strategic Systems Division provided assistance to the Director in the management of topographic systems development.

d. **Photogrammetry Division.** The Photogrammetry Division conducts applied research, development, design, and testing of photogrammetric data reduction systems, equipment, and techniques for topographic mapping, control, and position determination in support of Army weapons and general military applications. It also provides computer and statistical support for the Agency.

e. **Surveying and Geodesy Division.** The Surveying and Geodesy Division conducts applied research, development, design, and testing of surveying and geodetic systems and related geodetic control requirements including satellite-tracking equipment for geodetic purposes, for military mapping, and for combat operations.

f. **Graphics Division.** The graphics Division conducts applied research, development, design, and testing of cartographic, map reproduction and display systems, equipment, and techniques including terrain model and other related requirements, for the collection, preparation, dissemination, and display of topographic information.

7. **Evolution of the GIMRADA Organization.** In 1962, under the leadership of Colonel W. H. Van Atta, the directorate of the agency was reorganized to provide a military Deputy Director, an advisory staff of a Scientific Advisor and a Technical Advisor, an executive office headed by a civilian executive officer, a Director of Global Systems, and a Director of Tactical Systems. The positions of Director of Global Systems and Director of Tactical Systems were established to assist the Director in the management of the Corps of Engineers and the Army Materiel Command programs, respectively.

The reorganization of the Army in the early 1960's placed the responsibility for research and development of Army materiel with the Army Materiel Command. To avoid duplication and overlap of facilities and functions between the Corps of Engineers, with its base plant mapping facility and global operations, and the Army Materiel Command, a memorandum of understanding between the Commanding General, Army Materiel Command, and the Chief of Engineers was developed which provided, in part, the following:[2]

> The Chief of Engineers will retain primary responsibility for research and development of mapping and geodetic equipment, systems, and techniques in support of global systems and for operational mapping and geodesy.
>
> The Commanding General, Army Materiel Command, will have primary responsibility for research and development necessary

[2]Memorandum of Understanding between Commanding General, Army Materiel Command and the Chief of Engineers on the support to be provided AMC by Office, Chief of Engineers, pertaining to research and development of mapping and surveying equipment for the field armies, 1 August 1962.

to provide mapping and surveying equipment for the field armies.

To provide for coordination of the technical overlap, Army Materiel Command will have direct liaison with the U. S. Army Geodesy, Intelligence and Mapping Research and Development Agency and with the Office, Chief of Engineers.

The U. S. Army Geodesy, Intelligence and Mapping Research and Development Agency will conduct the research and development necessary to provide Army Materiel Command with the technical data required for initial specifications. Army Materiel Command will assist.

Army Materiel Command will have primary responsibility for preparation of the final procurement packages. The U. S. Army Geodesy, Intelligence and Mapping Research and Development Agency will assist.

The Army Materiel Command will have responsibility for funding its portion. Office, Chief of Engineers, will have responsibility for funding its program.

The organization established in 1962 under the leadership of Colonel Van Atta remained in force without significant change until 1965. By this time, the annual budget and the personnel strength were nearly double what they had been at the establishment of GIMRADA in 1960. The total personnel complement was approximately 200, and the annual budget was in the vicinity of $12,000,000.

Studies made in 1965 under the direction of Colonel L. L. Rall and his deputy director Lt. Colonel M. V. Jonah indicated a need for strengthening the organization in the area of central programming control and scheduling. Also, the concept of the separation of the "R" from the "D" (that is, the separation of research functions from development functions in the organizational alignment) was proposed.

At the same time, discussions were under way with the National Aeronautics and Space Administration (NASA) concerning a Technical Application Center for Geography which NASA was planning, possibly to fall under the direction of GIMRADA.

After much discussion within GIMRADA and numerous revisions, a plan for reorganization was finally submitted to the Office, Chief of Engineers, for approval. This plan called for a reorganization in two phases: the first to be implemented on approval by OCE, and the second to be further developed and implemented after some experience with the first phase.

Phase I called for a realignment of the directorate and the administrative offices of the Agency. The operating elements were grouped into two organizational segments — a Research Institute for Geodetic Sciences, and a Development Laboratories for Mapping and Geodetic Systems, thus separating research from development. Technical Plans and Systems Analysis Division was established within the Development Laboratories to perform dual functions as coordinating and staff agent for the Director of the Development Laboratories and as a line function in system development. By this time, the NASA Technical Applications Center for Geography had been dropped from further consideration by GIMRADA. Phase II was to be a further reorganization of the line functions within the Development Laboratories.

Phase I of the proposed plan was approved by OCE with some modification and was implemented in November 1965. The Directorate was realigned, eliminating the Scientific Advisor and Technical Advisor positions and the positions of Director of Global Systems and Director of Tactical Systems. New titles of Commanding Officer and Deputy Commanding Officer replaced the old titles of Director and Deputy Director. A Technical Director position was established with responsibility for the Plans and Programs Office and the field office at Wright-Patterson Air Force Base. An office of Administrative Services, headed by the Executive Officer, was also established.

After a limited trial period, Phase I proved to be unsatisfactory in several respects. Thus, under the direction of Colonel H. W. Fish, the Phase II reorganization plan included recommendations to correct the deficiencies. Proposed changes included the elimination of the Technical Director position as established. The position had actually been neither technical nor directive. These duties were to be assumed in dual roles by the Director of the Development Laboratories as Technical Advisor and the Director of the Research Institute as Scientific Advisor. The Deputy Commanding Officer was to serve in a dual role as Program Administrator supervising both the Program and Analysis Office and the Procurement Office. The Technical Plans and Systems Analysis Division was also eliminated. This latter change was made because the older arrangement simply did not work because of unnecessary layering resulting in confusion as to areas of responsibility. The Phase II plan also included a major realignment of the operating divisions of the Development Laboratories and the addition of a planning staff to the Office of the Director of the Development Laboratories. The operating divisions recommended for the Development Laboratories were an Advanced Mapping Division with Automated Cartography, Automated Compilation, Computational Systems, and Special Projects Branches; a Geographic Sciences Division with Geographic Applications, Geographic Information Systems, and Geography Branches; a Surveying and Geodesy Division with Astro-Geodetic, Electronics Surveying Systems, Geodetic Satellite, and Inertial Surveying Branches; and a Topographic Engineering Division with Electrogrammetric Systems, Engineering, Mechanics and Optics, and Reproduction Branches.

The Phase II plan was approved by OCE and implemented in November 1966, 1 year after the Phase I reorganization.

8. Redesignation as the U. S. Army Engineer Topographic Laboratories (ETL). The name, U. S. Army Engineer Geodesy, Intelligence and Mapping Research and Development Agency, given to the agency at its inception had never been completely satisfactory. First, it was too long, apparently trying to describe the entire operation of the Agency in the title. Second, and more importantly, the word "Intelligence" proved to be a problem in dealing with foreign nationals and in participating in international organizations.

Despite its shortcomings, the name had quickly become very well known. Consequently, there was not only a reluctance to change but also there was no consensus concerning a new name. Finally in early 1967, the Commanding Officer of the Agency submitted several suggested new names to OCE with a recommendation that one of them be adopted. On 7 April 1967, after rejecting all of the suggested names, the Chief of Engineers selected the new title: U. S. Army Engineer Topographic Laboratories (ETL). The redesignation was to be effective on 28 July 1967.[3]

9. Reorganization of 1968. In August 1967, an ad hoc group from the Army Scientific Advisory Panel was formed at the direction of the Assistant Secretary of the Army (R&D) to make a study of the Engineer Topographic Laboratories and the direction of the Army's efforts in research and development for mapping, geodesy, and military geographic intelligence. The group was chaired by a former Assistant Secretary of the Army for Research and Development, Mr. Hawkins. Their report[4] was submitted to the Chief of Staff of the Army in September 1967. It outlined the scope, content, and direction of Army mapping and geodetic research and development as conducted by the U. S. Army Topographic Laboratories. It identified the need for a systems approach in mapping, geodesy, and military geographic intelligence projects; the need for increased participation by educational institutions in ETL activities; and the need for a realignment of ETL's technical manpower resources including augmentation if required.

The report also pointed out the need for a reexamination by the Army and the Department of Defense of requirements for mapping, geodesy, and military geographic intelligence projects in the light of computer technology and optimally obtained source data. The report further noted that the Army was still operating on the outmoded philosophy that a line map is always the best or only manner to portray topographic information and that the Army had failed to recognize and properly exploit

[3] General Order No. 13, Office, Chief of Engineers, 31 July 67.

[4] Review of Activities and Plans, Engineer Topographic Laboratories, dated Sept 1967 by Ad Hoc Group of the Army Scientific Advisory Panel.

the full potentials of modern computer technology in providing terrain data to the commander in the field within responsive time periods and in new and more useful formats.

Consequently, the report recommended the establishment of a computer sciences capability within the U. S. Army Topographic Laboratories. Only in this manner could proper advantage of computer technology be taken in future developments and in the solution of unique topographic science problems using mathematical modeling and simulation techniques.

The report of the ad hoc group and internal studies of the organization structure led to the conclusion that the Phase II reorganization in November 1966 had not provided the optimum structure for efficient management and had to some degree created layering and overlapping of functions. Thus, a reorganization of ETL was developed and recommended to the Chief of Engineers on 9 February 1968.[5]

A major recommendation was to revise the mission statement. A more encompassing phrase "topographic sciences to include mapping, geodesy, and military geographic information" would better describe the area of interest of the Laboratories and would indicate that mapping, geodesy, and geographic information are merely parts of a larger concept of fully describing, portraying, and measuring the ground on which the Army operates.

OCE Regulation No. 10-1-13, 7 May 1968, assigned the newly stated mission and established the newly constituted organization of USAETL and rescinded ER 10-1-13, 15 September 1965. The following statements are extracted from that regulation.

> Establishment. The U. S. Army Engineer Topographic Laboratories, a Class II activity under the Chief of Engineers, was established as the U. S. Army Engineer Geodesy, Intelligence, and Mapping Research and Development Agency by General Order No. 22, Office of the Chief of Engineers, 2 August 1960, and continued in that status by General Order No. 29, Office of the Chief of Engineers, 3 October 1961. It was redesignated the U. S. Army Engineer Topographic Laboratories by General Order No. 13, Office of the Chief of Engineers, 31 July 1967.
>
> Mission. The U. S. Army Engineer Topographic Laboratories is the principal field activity of the Army for accomplishing research and development of equipment, procedures, and techniques applicable to the topographic sciences to include mapping, geodesy,

[5] "Reorganization of the U. S. Army Engineer Topographic Laboratories," Letter, CO ETL to Chief of Engineers, 9 February 1968.

and military geographic information. The Chief of Engineers may assign work to these laboratories under research and development projects utilizing either RDTE funds or other appropriate funds.

The organization approved by ER 10-1-13 is shown on the chart dated 22 April 1968 in Appendix A. Several highly significant changes in organization were effected by this reorganization. First, the position of Technical Director was re-established. The Technical Director reported directly to the Commanding Officer and had line responsibility for the technical operations of the entire organization. This position, which had not been provided since the reorganization of 1962, was needed to develop and maintain a coherency of the laboratory effort and to tie together the technical efforts of the Research Institute, the Field Office, the technical divisions, and the new Computer Sciences Laboratory.

Second, the management structure was strengthened and layering was reduced by consolidating all planning, programming, and technical operations performed by several elements in the old organization into a single Plans and Operation Office. Included in the responsibilities of this office were the development and maintenance of a long-range technical plan covering the entire mission of the Laboratories and the coordination of interagency activities including liaison with other agencies within the mapping community and with user agencies.

Third, the new organization provided for a scientific advisory panel reporting directly to the Commanding Officer as recommended by the ad hoc group report.

Finally, to correct the deficiency noted in the ad hoc group report that the Army had failed to properly exploit the full potential of computer technology in the solution of terrain data problems, a Computer Sciences Laboratory was established. The mission of the Computer Sciences Laboratory was to conduct research and development oriented toward the solution of topographic science problems using mathematical modeling, computer technology, and systems analysis. The laboratory was to incorporate these advances into future topographic systems, to conduct research and development in the disciplines of applied mathematics and computer sciencies for topographic applications, and to provide support and services to other elements of the Laboratories in computer applications and programming. The 1968 organization remained essentially intact except for the addition of a Photographic Interpretation Research Division by transfer from the U. S. Army Cold Regions Research and Engineering Laboratories in June 1970. The authorized strength at the close of FY 71 was 239 civilians and 15 military personnel.

10. Integration Into the U. S. Army Topographic Command. The U. S. Army Engineer Topographic Laboratories became a subordinate command of the U. S. Army

Topographic Command when it was established 1 September 1968 as a Class II activity under the Chief of Engineers. Other subordinate commands of the U. S. Army Topographic Command were U. S. Army Engineer Topographic Production Center, U. S. Army Engineer Topographic Data Center, and U. S. Army Engineer Topographic Troop Command.

V. ADMINISTRATIVE ACTIVITIES

11. **Commanders of GIMRADA – ETL through FY71.** The command of GIMRADA and ETL shows frequent changes through FY71:

COMMANDING OFFICERS

Colonel L. L. Haseman	First Director, GIMRADA	1 Aug 60 to 23 Jul 61
Colonel W. H. Van Atta	Second Director, GIMRADA	24 Jul 61 to 30 Jun 64
Colonel Lloyd L. Rall	Third Director and First Commanding Officer, GIMRADA	1 Jul 64 to 9 Jan 66
Colonel Hamilton W. Fish	Second Commanding Officer, GIMRADA, and First Commanding Officer, ETL	10 Jan 66 to 31 Jul 67
Colonel E. G. Anderson	Second Commanding Officer, ETL	1 Aug 67 to 30 Jun 68
Colonel John R. Oswalt, Jr.	Third Commanding Officer, ETL	1 Jul 68 to 31 Jul 71
Colonel John E. Wagner	Fourth Commanding Officer, ETL	1 Aug 71 to

DEPUTY COMMANDERS

Mr. William B. Taylor	September 1960 to December 1961
LTC Robert P. Graves	December 1961 to January 1965
LTC Maxwell V. Jonah	January 1965 to June 1966
LTC William R. Cordova	June 1966 to December 1967
Colonel Colin M. Carter	December 1967 to December 1967 (2 weeks)
Major William R. Revell	January 1968 to February 1968 (2 weeks)
Major Alan L. Laubscher	March 1968 to June 1968
LTC George N. Simcox	June 1968

12. **Key Civilian Positions, GIMRADA–ETL.** Key civilian positions in GIMRADA and ETL during the 1960 to 1970 period are shown below. (Technical personnel responsible for development during this period are listed in Appendix E.)

E. A. Bjerhammer	–	Director, Research Institute
Bela J. Bodnar	–	Acting Director, Research Institute
William C. Cude	–	Technical Director, GIMRADA Technical Advisor, GIMRADA
Robert E. Dudley	–	Acting Chief, Photogrammetry Division
Randell D. Esten	–	Chief, Photogrammetry Division Chief, Photogrammetry and Mapping Division
Stephen W. Gibson	–	Chief, Graphics Division
James E. Gillis, Jr.	–	Chief, Intelligence Division Chief, Geographic Intelligence Division Associate Technical Director, ETL Acting Director, Computer Sciences Laboratory
Donald R. Handberg	–	Executive Officer
Robbins G. Hickson	–	Chief, Systems Control Office Director, Tactical Systems Acting Associate Director, Development Laboratories
Kenneth R. Kothe	–	Chief, Geographic Sciences Division
Robert G. Livingston	–	Chief, USAF Liaison Office Chief, Field Office, W-PAFB
Gilbert G. Lorenz	–	Chief, Strategic Systems Division Director, Global Systems Director, Development Laboratories Technical Director, ETL
Robert Macchia	–	Chief, Advanced Mapping Division Chief, Automated Mapping Division
Charles R. Manor	–	Chief, Surveying & Geodesy Division
Howard O. McComas	–	Chief, Strategic Systems Division Chief, Technical Plans & Systems Analysis Division Chief, Topographic Engineering Division
Frank A. McFarland	–	Chief, Graphics Division
Desmond C. O'Connor	–	Director, Research Institute Scientific Advisor, ETL

John T. Pennington	–	Chief, Research and Analysis Division Technical Advisor, GIMRADA Technical Director, GIMRADA
John R. Richardson	–	Associate Technical Director, ETL Chief, Plans & Operations Office
Hellmut Schmid	–	Scientific Advisor, GIMRADA
Melvin C. Shetler	–	Chief, Surveying & Geodesy Division

13. Cost of Development. Available records indicate that the cost of development up to FY 40 was minimal: about $37,000. Beginning in FY 40 with the United States involvement in World War II, sudden increases in expenditures occurred for mapping research and development to field and equip military topographic units for wartime operations. From FY 40 through FY 44, the largest expenditures occurred in the map reproduction area to provide mobile reproduction facilities for the Army Topographic Battalion and Corps Topographic Companies. In FY 44 expenditures on photomapping increased markedly and expenditures on map reproduction were reduced in comparison with the previous war years.

Following World War II, there was another marked increase in funding for mapping and geodesy research and development in a deliberate program to re-equip army units which had been equipped primarily with commercial equipment during World War II. Emphasis was placed on rugged, lightweight, mobile equipment designed to meet established military characteristics and requirements.

Another change in expenditure levels came at the outbreak of the Korean War with a better appreciation within the Army and the Department of Defense of the importance of the availability of accurate topographic data for military operations. They recognized the need to increase markedly the speed and rate at which these data were produced.

From FY 51 until FY 57, expenditures remained at approximately the same level. Starting in FY 58, there was a steady increase in expenditures due to the development of the long-range missile and the successful launching of an earth satellite. These developments and the associated technology not only changed the patterns and concepts of military operations, thus affecting the requirements for topographic and geodetic data, but also provided the basic tools, which, if properly exploited, could provide the means for satisfying these requirements.

Research and development funding for FY 40 through FY 70, with the exception of FY 46, is shown in Table 1.[6] Two sources of funding are shown for FY 63 and beyond. (As noted previously, the 1963 reorganization of the Army placed the responsibility for research and development of military equipment with the Army Material Command.)

Table 1. R&D Funding, FY40 through FY70

Fiscal Year	OCE	AMC	TOTAL
1940	$ 87,400		$ 87,400
1941	267,544		
1942	257,732		
1943	256,476		
1944	158,964		
1945	147,246		
1946	–		
1947	411,047		
1948	362,983		
1949	427,106		
1950	530,530		
1951	1,172,225		
1952	1,351,009		
1953	1,279,202		
1954	1,245,219		
1955	1,141,955		
1956	1,315,500		
1957	1,717,800		
1958	2,763,873		
1959	3,746,691		
1960	5,701,178		
1961	4,504,521		
1962	6,838,000		
1963	7,621,492	$3,287,000	$10,908,492
1964	10,576,071	3,254,885	13,830,956
1965	8,350,000	3,268,000	11,618,000
1966	6,993,945	2,258,338	9,252,283
1967	6,573,988	3,458,255	10,032,243
1968	4,155,001	1,050,000	5,205,001
1969	7,689,000	1,728,000	9,417,000
1970	6,579,984	5,431,000	12,010,984

[6] Data through FY45 from History of Development, MP-1 Photomapping 1946, MP-2 Map Reproduction 1946, and MP-3, Surveying & Navigation 1947. Data for FY47 through FY70 from the files of Plans and Operations Office, ETL.

14. Facilities. As the number of personnel engaged in research and development in the topographic sciences and the expenditure of funds have increased over the years, so has the requirement for building space and laboratory facilities. Present facilities are far from adequate, and planning has been under way for a number of years to provide a better facility. Approval for the facility was finally included in the FY 72 construction program, with completion scheduled for approximately July 1974.

When the Engineer Board occupied the new facility at Fort Belvoir in 1942 (now known as the Mobility Equipment Research and Development Center), space in Building 320 and four small offices in Building 316 were allocated to the Mapping Branch of Technical Division I. A little over half of Building 320 was designated as the Mapping Branch Laboratory area and the remainder was a photographic laboratory providing duplicating and general photographic services for the Engineer Board. The space was more than adequate at the time. However, with the acquisition of equipment and the increase in staff in the immediate post-war years, a need developed for additional space. This space was provided when a new Materials Laboratory building was completed and occupied. The old Materials Laboratory building, Building 318, was refurbished and assigned to the Topographic Engineering Department, thus more than doubling the laboratory and office space for mapping and geodetic research and development.

Together with some additional office space provided in Building 316, these facilities were adequate until the early 1960's when there was further increase in staff. At this time, it was also necessary to have extensive clean-room facilities installed in Building 318 to accommodate the highly sophisticated precision equipment then under development. Since additional building space within the ERDL compound was not available, it was necessary to look elsewhere for space. For a short period in the early 1960's, one of the classrooms on the third floor of the Wheeler building was made available by the Engineer School for the Research and Analysis Division. For additional space, it was necessary to resort to leased office trailers parked within the compound in the areas around the permanent laboratory buildings. Later in 1966, through the General Services Administration, approximately 9000 square feet of leased space in a building at the corner of Washington and Prince Street in Alexandria, Virginia, became available to house the Research Institute.

Early in the 1960's a building was designed for construction in the parking lot area adjacent to Building 320 to house a part of the GIMRADA complement. With the reorganization of the Army in 1962, however, there was some doubt that GIMRADA would continue to be located in the ERDL complex at Fort Belvoir. At the time, in fact, some consideration was being given to rehabilitating the Fremont Building at the Army Map Service for a GIMRADA facility. It was therefore decided, practically on the eve of start of construction, to locate the new building at the Army Map Service. It was intended that the newly constructed building, designated the Emory Building, would

be occupied by GIMRADA personnel. Although desk space was provided for GIMRADA, for a while the building really never proved useful for its intended purpose and soon reverted to total use by the Army Map Service.

At the close of FY 70, ETL occupied 33,260 square feet of laboratory space at Fort Belvoir on loan from the U.S. Army Mobility Equipment Research and Development Center, 27 leased office trailers, and 9000 square feet of leased space in Alexandria, Virginia. Plans were being developed for the construction of a 100,000 square foot facility on a site at Fort Belvoir, Virginia, known as the "Protective Structures Site." This area will also provide sites for the Coastal Engineering Research Center (CERC), Board of Engineers for Rivers and Harbors (BERH), Water Resources Institute (WRI), and Engineer Reactor Group (USAIRG).

15. **Education and Training Program.**[7] Programs of study for engineers and scientists of GIMRADA were started in 1961. The stated objectives of the programs were to improve the overall technical capability to meet increasingly complex engineering requirements, to improve the professional and technical capability of individual employees, to provide an increasingly strong incentive for young engineers and scientists to remain with the agency on a career basis, and to assist in the recruitment of college graduates for careers with the agency. The program included two major areas: a graduate resident study program at both the master's and doctorate level, and a program of parttime training in government and non-government facilities. Through the years, the Agency has also given strong support to employee participation in other training opportunities available outside the regular agency programs. Table 2 is a listing of personnel who have participated in these programs since their inception.

16. **Awards Program.** Awards programs to recognize special acts and services in the Department of the Army, the Corps of Engineers, and the ETL were limited in scope and number until the late 1950's and early 1960's. Until that time, the major recognition awards were the Exceptional Civilian Service Award and the Meritorious Civilian Service Award – both of which date from World War II. In later years, both the Army Research and Development Achievement and the Secretary of the Army's Research and Study Fellowship Awards programs were established. The establishment of the Army Science Conferences offered another means of recognition of significant scientific achievement by Army Research and Development Laboratory personnel. A number of ETL personnel have earned special recognition in these awards programs.

In 1968, the Commander's Awards for Scientific and Technological Achievement and for Leadership[8] were established within ETL, and the awards have been made

[7] USAETL Memo 350-1.

[8] ETL Regulation Number 672-1.

Table 2. Training Program Participants

Full Time Graduate Training Under ETL Program				
Name	Date	School	Training	Level
Donald R. Barnes	Sep 1961 to Aug 1962	Ohio State	Photogrammetry	Masters
Walter E. Boge	Sep 1962 to Aug 1963	Syracuse	Photogrammetry Geodesy	Masters
Reuben D. Cook	Sep 1962 to Jun 1963	Syracuse	Photogrammetry	Masters Completed
James R. Skidmore	Sep 1962 to Jul 1963	Syracuse	Photogrammetry	Masters
James E. Stilwell	Sep 1963 to Aug 1964	Illinois	Photogrammetry Geodesy	Masters
James W. Gladden, Jr.	Sep 1964 to Aug 1965	Georgetown	Chemistry	Masters
Carl R. Friberg, Jr.	Jan 1965 to Jan 1966	Ohio State	Geodesy	Masters
Desmond C. O'Connor	Aug 1965 to Aug 1966	Illinois	Photogrammetry/ Optics	Doctorate Completed
Andrew J. Bondurant	Sep 1965 to Aug 1966	Syracuse	Photogrammetry	Masters
F. Raye Norvelle	Sep 1965 tn Aug 1966	Syracuse	Photogrammetry	Masters
Armando Mancini	Sep 1966 to Sep 1967	Georgetown	Astronomy	Doctorate Completed
Allan Kiisk	Sep 1966 to Mar 1968	Stanford	Electronics	Masters
Donald J. Skala	Sep 1966 to Sep 1967	American	Mathematics	Masters
George S. Barber	Sep 1967 to Sep 1968	Ohio State	Photogrammetry	Masters
Wesley E. Sanburn	Sep 1967 to Aug 1968	George Washington	Mathematics	Masters
Val E. Sellers	Sep 1968 to Aug 1969	Purdue	Photogrammetry	Masters Completed
Victor E. Shely	Sep 1968 to Aug 1969	Midwestern	Mathematics	Masters
Richard Malone	Sep 1968 to Aug 1969	John Hopkins	Space Technology	Masters Completed
Joseph F. Hannigan	Sep 1969 to Aug 1970	Catholic U.	Physics	Doctorate
Bruce Zimmerman	Sep 1969 to Aug 1970	Virginia Polytechnic Institute	Mechanical Engineering	Masters
Kent T. Yoritomo	Sep 1970 to Aug 1971	George Washington	Engineering Administration	Masters
Marvin Gast	Sep 1970 to Aug 1971	Maryland	Geography	Doctorate

Table 2 (cont'd)

Other Full Time Graduate Training			
Name	Date	School	Level
Robert P. Macchia	Sep 1963 to Jun 1964	Virginia	Certificate as Fellow, National Institute of Public Affairs
Randall D. Esten	Sep 1964 to Jun 1965	Princeton	Certificate as Fellow, National Institute of Public Affairs
Lawrence F. Ayers	Sep 1965 to Jun 1966	Indiana	Master of Public Administration
James E. Gillis, Jr.	Aug 1965 to Jun 1966	Industrial College of Armed Forces	Diploma–Management of National Security Resources
		George Washington	Master of Sciences Degree in Management and Business Administration
M. Stromberg	Sep 1967 to Jun 1968	Maryland	Master of Arts in Economics

annually since that time. In 1969, the ETL established the Gallery of Distinguished Civilian Employees[9] in which outstanding civilian employees are recognized by the display of their portraits in the gallery.

Recipients of the various awards in the 1960 to 1970 period were as follows:

a. **Exceptional Civilian Service Award**

Gilbert G. Lorenz, 1968-1970. For exceptional performance of duty as Technical Director, ETL, from 1 April 1968 to 31 January 1970. His extraordinary leadership, judgment, administrative ability, and professional skill were instrumental in effecting a major redirection of programs to take the greatest possible advantage of advances in technology and system analysis.

b. **Meritorious Civilian Service Award**

(1) **John T. Pennington[10], 1960-1966.** For exceptional leadership in accomplishing high priority programs in the mapping and geodetic fields including development of a highly complex mapping system.

(2) **Melvin C. Shetler, 1961-1964.** For exceptional leadership and administrative capabilities in accomplishing the development of high priority mapping programs including SECOR and the long-range surveying system.

[9] ETL Regulation Number 690-6.

[10] This was the second Meritorious Civilian Service Award presented to Mr. Pennington. The first was presented in 1944 for work on development of photomapping equipment.

(3) **John G. Armistead, 1962-1964.** Through his technical knowledge and leadership abilities, he accomplihsed the first successful operation of SECOR.

(4) **C. Edward Westerman, 1947-1971.** As Assistant Chief of the Surveying and Geodesy Division, he has shown commendable capability as a Senior Project Engineer and a supervisor in carrying out successful research and development programs of highest priority throughout the scientific disciplines in the surveying and geodesy fields.

c. Army Research & Development Achievement Awards

(1) **1967—M. Stromberg, J. D. Mayer, E. R. DeMeter, K. T. Yoritomo, E. F. Burzynski.** Development of the Universal Automatic Map Compilation Equipment (UNAMACE). This revolutionary automated high speed stereo-compilation equipment provides the Army with an unprecedented superiority in the field of mapping and automatic photographic data reduction.

(2) **1968—K. T. Yoritomo.** For planning, executing, and directing a series of scientific and engineering studies and investigations leading to the establishment of a comprehensive R&D program to provide a military all-weather mapping capability.

(3) **1969—Dr. Angel A. Baldini.** Development of the Baldini theory to solve the problem of determining ground station positioning with respect to the center of the earth's mass leading to the World Geocentric Geodetic System and a mathematical figure of the earth based only on astrogeodetic methods.

(4) **1969—Mr. John G. Armistead, Mr. G. W. Bunch, Mr. Frederick Gloeckler, Mr. Richard T. Malone, Mr. Robert Nichols, Mr. Walter Simpson.** Five year multimillion dollar R&D achievement culminating in operational satellites and miniaturized ground stations for the Geodetic SECOR System.

(5) **1970—Mr. Maurits Roos.** Development and implementation of a means to automate precise point measuring on aerial photography.

(6) **1970—Dr. Desmond O'Connor, Dr. Pi-Fuay Chan.** For research on one-dimensional, high-resolution array systems using mechanical and electronic perturbation.

d. Secretary of the Army's Research and Study Fellowship Award

(1) **1969-1970—B. B. Scheps.** Conduct a study in the area of terrain and topographic data processing.

(2) **1964-1965—B. J. Bodnar.** Determine the state-of-the-art in the field of physical geodesy.

e. **Army Science Conference Papers**

(1) **1966—L. A. Gambino.** A geometric simultaneous multistation determination with constraints using data from geodetic satellites.

(2) **1968—L. A. Gambino.** Second order regression progress in geometric satellite data reduction.

f. **Commander's Award for Scientific and Technological Achievement**

(1) **1968—Kenneth D. Robertson.** For development of highly advanced surveying instruments and techniques which promise radical changes in present geodetic surveying practices.

(2) **1969—Ernest M. Stiffler.** For his contribution to an Advanced Automatic Compilation System.

(3) **1970—Pi-Fuay Chan.** For planning and executing systems for more accurate position and velocity detecting systems by perturbating the input image signals on an array sensor. His work opened the way for replacement of film in astronomical cameras to yield real time values for stellar and satellite coordinates.

g. **Commanders Award for Leadership**

(1) **1968—W. Howard Carr.** For his excellent performance in planning, organizing, and directing his Branch's program for development of a Semi-Automatic Cartographic System.

(2) **1969—Donald G. Orr.** For his work in planning, organizing, and executing Project Sand, a project to locate suitable sand and gravel in the Mekong Delta area.

(3) **1970—Oscar W. Bowker.** For outstanding supervisory and managerial capabilities in efficiently directing the research and development programs for several top priority tasks in the Surveying and Geodesy Division. Particularly for the exceptional work accomplished under his leadership on the lightweight gyro azimuth theodolite and the Position and Azimuth Determining Systems.

h. **Gallery of Distinguished Civilian Employees**

(1) **1970—William C. Cude, John T. Pennington.**

(2) **1971—Randall D. Esten.**

VI. RESEARCH AND DEVELOPMENT PROGRAMS

17. **Research and Development Programs Through World War II.** Most of the research and development work in mapping through World War II was carried on under projects assigned to the Engineer Board or its predecessor, the Board on Engineer Equipment, by the Chief of Engineers.

The Army Map Service did additional research, particularly in the map reproduction field both on its own initiative and at the request of other agencies such as the Army Air Forces. This research was not carried under specific project numbers.

The work on photomapping or photogrammetric research was accomplished primarily by the Engineer Detachment at Wright Field.

The principal projects assigned by the Chief of Engineers, in order of their opening dates and grouped in areas of general projects, photomapping, map reproduction, and surveying and in order of their authorization, were as follows:

a. **General Projects**

(1) 1-235, Opened 25 July 1935; Organization, Photogrammetric and Reproduction Equipment of a Topographical Battalion. To define the function and draw up a Table of Organization and a Table of Basic Allowances for the Engineer Topographic Battalion, Army, and the Engineer Topographic Battalion, GHQ. Closed 6 September 1944.

(2) SP205G, Opened 5 May 1939; General Doctrine for Mapping in Enemy Territory. To study the general doctrine of mapping in enemy territory. Became inactive 1 June 1940.

(3) SP286, Opened 19 July 1939; Organization and Equipment for Corps Engineer Mapping Unit. To define the function and draw up a Table of Organization and a Table of Basic Allowances for an engineer mapping unit to be attached to Corps Engineer Headquarters (later known as the Engineer Topographic Company, Corps). Closed 1 February 1943.

(4) EB139, Opened 19 March 1942; Organization and Equipment of Topographic Units Assigned to Army Air Force. To assist in the preparation of a Table of Organization and a Table of Basic Allowances for engineer mapping units assigned to the Army Air Force. Closed 14 February 1943.

b. Photomapping Projects

(1) 1-205, Opened 30 June 1933; Mapping in Enemy Territory by the Use of Aerial Photographs. To consider all possible methods of mapping in enemy territory with emphasis on speed; the use of the aerocartograph or similar instruments was contemplated. In December 1935, the directive for this project was modified to include the determination of the equipment needed.

(2) 1-209, Opened 30 June 1933; Miscellaneous Engineer Equipment Required for Aerial Mapping. To investigate miscellaneous equipment used for aerial mapping.

(3) S-216, Opened 26 February 1934; Portable Stereoscope. To develop a portable stereoscope suitable for field use.

(4) SP-205C, Opened 5 May 1939; Improvements in the Battle Map. To improve the accuracy and reduce the time of production of the 1:20,000 battle map.

(5) SP-205D, Opened 5 May 1939; Map Substitutes From Contoured Wide-Angle Photographs. To investigate methods of preparing a contoured wide-angle photograph for use as a hasty map substitute and of preparing mosaics from such photographs as substitutes for the T3A composite.

(6) SP-205E, Opened 5 May 1939; Wide-Angle Mapping Equipment. To develop photogrammetric equipment for use with the T5 camera.

(7) SP205F, Opened 5 May 1939; Miscellaneous. To investigate subjects related to aerial mapping not covered by other projects.

(8) SP216-1, Opened 5 May 1939; Portable Pocket Size Magnifying Stereoscope. To develop a magnifying pocket spectacle-type stereoscope as recommended in Infantry Board Report 1012, 12 January 1939.

(9) SP216-2, Opened 5 May 1939; General-Purpose Mirror Stereoscope for Use by Other Areas. To develop a portable magnifying mirror type stereoscope.

(10) MP205C(3), Vertical Control for Aeronautical Charting. To find means of determining elevations on aerial photographs by devices installed in the photographic airplane.

(11) MPS408, Opened 17 April 1943; Investigation and Modification of Photomapping Equipment and Technique. To investigate photomapping equipment and techniques. (This was a general service project on photomapping.)

(12) MP488, Opened 30 March 1944; Rectifying Camera. To develop a rectifying camera capable of rectifying the obliques produced by the tri-metrogon mount and the split vertical installation and suitable for mounting in a truck with van-type body.

(13) MP593, Opened 17 July 1945; High Oblique Multiplex Projectors. To develop a multiplex projector for use in preparing topographic maps from high oblique photography such as that obtained by the tri-metrogon system.

(14) MPS 673, Opened 13 August 1945; Application of SHORAN to Mapping. To expedite the application of SHORAN to map control. (SHORAN is an electronic navigation device developed for the Army Air Forces to facilitate bombing through overcast.)

c. Map Reproduction Projects.

(1) 14, Opened 12 March 1923; Mobile Map Reproduction Plant. To develop a mobile reproduction plant as required by the Army Topographic Battalion.

(2) P-89, Opened November 1925; Map Reproduction Equipment Regimental. To consider all map reproduction equipment needed by the Engineer Combat Regiment.

(3) 1-61, Opened 15 May 1930; Improved Dietzgen Printing Frame. To determine the suitability of a curved printing frame newly designed by the Eugene Dietzgen Company as a substitute for the current blue printing frame.

(4) S-109, Opened 5 October 1932; Fluorigraph Screens. To study the Fluorigraph screen, invented by Mr. Eddy [illegible] of the Netherlands, to permit photostating without elaborate equipment.

(5) 1-75, Opened 14 November 1932; Ozalid Developing Tubes. To develop a larger Ozalid developing tube as requested by the 3rd Engineers.

(6) S-114, Opened 30 June 1933; Bromide Reproduction Process. To develop the bromide reproduction process — a simplified photostatic process.

(7) I-210, Opened 16 November 1939; Mobile Copying Camera. To develop a truck- or trailer-mounted copying camera capable of producing copy negatives up to 24 by 24 inches.

(8) SP309, Opened 22 January 1940; Offset Reproduction of Aerial Photographs. To investigate promising methods of lithographic offset reproduction of aerial photographs.

(9) SP319, Opened 5 June 1940; Mobile Map Reproduction Train, Topographic Battalion. To develop a mobile map reproduction train for the Army Topographic Battalion.

(10) SP210B, Opened 24 July 1941; Development of Microfilming in Conjunction with Map Reproduction. To investigate, in cooperation with the Engineer Reproduction Plant, the use of film miniatures prepared by microfilming in the field of map reproduction.

(11) MP286C, Opened 14 July 1942; Map Distribution Trucks. To design a map distribution truck to facilitate sorting, packaging, and addressing maps.

(12) MP304C, Opened 14 July 1942; Mobile Projection Printer (20 by 20 inches). To develop a mobile rapid projection printer capable of enlarging from 9 by 9 inch wide-angle negatives up to 20 by 20 inches.

(13) MP363, Opened 15 September 1942; Lithographic Printing Inks. To prepare specifications for lithographic printing inks for field map reproduction and evolve methods of testing the inks procured.

(14) MP404, Opened 16 April 1943; Portable Reproduction Equipment for Task Forces. To develop portable reproduction equipment for Task Forces smaller than those with a Corps Topographic Company. This equipment is to include a copying camera, a plate processing apparatus, and an offset press.

(15) MPS409, Opened 17 April 1943: Investigation and modification of Map Reproduction Equipment and Techniques. To investigate techniques and equipment for map reproduction.

(16) MP580, Opened 20 July 1945; Airborne Camera, 24 by 30 inch, and Plate Processing Equipment. To develop an airborne 24- by 30-inch copying camera and airborne plate processing equipment.

(17) MP581, Opened 20 July 1945; Airborne Press, Lithographic Offset, 22½- by 29-inch. To develop a lightweight, compact, airborne 22½- by 29-inch lithographic press.

d. **Surveying Projects**

(1) S-33, Opened 21 March 1928; Prismatic Compasses. To develop a new prismatic compass for the infantry as proposed by the Infantry Board. Closed 11 March 1929.

(2) S-86, Opened 24 February 1930; Infantry Compass. To modify the Standard Engineer Prismatic compass into a lensatic type in accordance with the recommendations of Infantry Board Report 503. Closed 30 September 1932.

(3) SP-280, Opened 21 October 1938; Marching Compass. To find a commercial magnetic compass, with characteristics as specified by the Infantry Board, to replace the standard watch compass. Closed 23 March 1943.

(4) SP-321, Opened 25 July 1940; Military Theodolites. To devel an American 1-second reading theodolite similar to known European instruments for . by Engineer Troops engaged in surveying. Project still open at end of WWII.

(5) SP333, Opened 25 April 1941; Map Board. To develop a map board conforming to military characteristics presented by the Field Artillery. Closed 13 March 1943.

(6) SP349, Opened 17 February 1942; Navigation in Mobile Warfare. To investigate the methods and equipment of celestial navigation and dead reckoning for use in desert warfare. Closed 23 March 1943.

(7) MP354, Opened 4 August 1942; Triangle Slide Rule (Short Base). To develop a slide rule, graduated in mils, for use by the Field Artillery in the solution of short base triangle problems. Closed 13 March 1943.

(8) MP367, Opened 14 October 1942; Clinometer for Mountain Troops. To develop a surveying clinometer suitable for mountain troops. Closed 13 March 1943.

(9) MP349B, Opened 23 November 1942. Land Sextant. To develop a land sextant to replace the standard A12 octant in navigation equipment Set No. 1. Closed 23 March 1943.

(10) MP387, Opened 15 February 1943; Lighting Equipment for One-Minute Transit. To develop suitable night illumination for the standard 1-minute reading transit. Closed 30 August 1943.

(11) MP379, Opened 9 March 1943; Distance Finder. To develop an instrument similar to the German gap measurer. Closed 23 March 1943.

(12) MPS410, Opened 17 April 1943; Investigation and Modification of Surveying Equipment and Techniques. To investigate surveying techniques and equipment. A general service project on surveying. Project still open at the end of WWII.

(13) MP415, Opened 7 June 1943. Comparator (Measuring Engine). To develop a comparator suitable for measuring the distances of stars on plates exposed in a zenith camera. Closed 21 June 1945.

(14) MP475, Opened 3 November 1943; Simplified Zenith Camera. To develop a compact, lightweight zenith camera of approximately 12-inch focal length for astronomic position finding for use by the Army Air Forces and Engineer Mapping Units. Closed 21 July 1945.

18. Research and Development Progress Through World War II.

a. **General.** Most of the research and development activity through the 1930's concerned the role of aerial photography in military mapping. The Engineer Detachment began its investigations in the 1920's by cooperating with the Air Service in efforts to perfect the aerial mapping camera.

Based on Major Bagley's tri-lens camera developed in World War I, a series of multiple lens cameras was developed, culminating in the five-lens T3A. This camera remained the precision mapping camera of the United States Army until 1940 when the wide-angle lens was introduced. The T3A camera had five 6-inch focal length, F/6.8 aperture lenses, each exposing a 5.5-inch by 6-inch negative. The lenses were clustered, with the central lens aimed vertically and the other four spaced at 90° intervals around the central lens and tilted at 43° to the vertical. A tandem configuration with two of these cameras, one crabbed 45° with respect to the other, produced a composite photograph (after rectification and assembly) covering an angular field of about 140°.

Preparation of map products from aerial photographs was investigated during the 1930's through a series of mapping tests conducted to establish suitable methods and equipment. The products required were a mosaic at photographic scales; a planimetric tactical map at 1:62,500; and a planimetric fire-control data sheet, called a provisional battle map, at photographic scale. These tests and other investigations led to the development of the progressive mapping scheme. This scheme more than fulfilled the original objectives. By using stereoscopic plotting devices, topographic as well as planimetric maps could be produced. Furthermore, control could be extended by photogrammetric methods into "enemy" territory from a strip of "occupied" territory to provide fire control data. The progressive mapping scheme called for the preparation in sequences of: (1) a composite at 1:40,000 made by tandem T3A photography; (2) a planimetric provisional battle map at 1:20,000 compiled by tracing from tandem T3A photography; and (3) a topographic battle map at 1:20,000 with a contour interval of 50 feet, compiled from single T3A camera photography.

From studies of the organization and equipment needed for topographic mapping, it was concluded that ordinary mapping needs of combat units should be supplied by the Army Topographic Battalion—a field organization. The GHQ Topographic Battalion should be used to supplement field work, reproduce large quantity orders, and supply the needs of the communication zone and of GHQ units.[11] Both battalions should be organized into four companies: Headquarters and Service Company, Surveying Company, Photogrammetric Company, and Reproduction Company. Later in 1939, the Engineer Board suggested the need for a mapping unit to be attached to Corps Engineer Headquarters to prepare large-scale aerial photographs, mosaics, contoured maps of small areas and overprints. Therefore, Tables of Organization and Equipment for the Engineer Topographic Company, Corps were developed.[12]

Soon after the United States entered World War II, it became evident that the Air Forces would require assistance in compiling and reproducing their aeronautical charts. Consequently, two additional types of engineer mapping units, the Engineer Topographic Company, Aviation, and the Engineer Air Force Headquarters Company, were organized and assigned to the Air Force.

While the progressive mapping scheme and the techniques and equipment used in tests of the scheme more than fulfilled the original objectives set forth in 1933, the products did not fully satisfy the needs of the Artillery and the Infantry. The accuracy achievable in the topographic battle map was not adequate for the Artillery requirement for 60 percent effective artillery fire of 33 yards horizontally and 25

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11. "Organization and Equipment of Topographical Battalion," Engineer Board Report 531, 18 April 1938.

12. "Corps Mapping Unit," Engineer Board Report 583, 27 September 1939.

feet ver ically. The time requirement for production was excessive—2 to 3 weeks after receipt of photography. More realistically, there was an urgent need for a map to be available in 12 to 24 hours. The T3A composite photography had failed to meet this need partly because of the poor quality of reproduction.

While the investigations and tests from 1933 to 1939 were based almost entirely on the use of the T3A composite photography and normal angle multiplex equipment, the Engineer Detachment became interested in single-lens, wide-angle photography[13] in 1935. In that year, Heinz Gruner, a German national employed by the Engineer Detachment, returned from Germany with word that the Zeiss firm was using such a camera in conjunction with a wide-angle, multiplex projector. This equipment was procured from Carl Zeiss, Inc., for testing in 1936. The Air Corps procured the camera and the Corps of Engineers procured two sets of wide-angle multiplex projectors and a reduction printer. The Zeiss camera was tried out in the mapping tests of 1937, hut it failed mechanically. It was tried again in 1938, but the photographs could not be used because the multiplex equipment was not suitable. The reduction printer did not compensate for lens distortion in the camera.

In spite of these failures, interest in wide-angle photography remained high. In the meantime, the Bausch and Lomb Optical Company had designed a wide-angle lens called the metrogon, a lens of 6-inch focal length based on the Zeiss topogon lens design. The Air Corps began procurement of these lenses in 1938 and also started the development of the T5 wide-angle mapping camera.

In view of these developments, and following a Military Mapping Service Test by the 29th Engineers in 1939 employing the T3A camera, the Chief of Engineers set up a meeting in Washington to discuss the best mapping procedures and the best type of equipment. This mapping conference was held in Washington from 4 to 7 March 1940. Two rather surprising yet crucial decisions resulted from the conference. The first decision was to cease procurement of normal-angle mapping equipment. This meant abandoning the T3A which had been the standard mapping camera since the mid-1920's. The second decision was to accept the K3B[14] camera equipped with a wide-angle metrogon lens as a suitable camera for precise mapping. These decisions were made even though the wide angle mapping equipment had not been tested in this country. The conference did, however, request the continued development of a precision wide-angle mapping camera.

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[13]The term "wide angle" applies to lenses with a total field of more than 60°.

[14]The K3B was designed originally as a general-purpose camera. It had interchangeable lines of 6-inch, 8.25-inch, 12-inch and 24-inch focal lengths, between the lens shutter, a vacuum back, and produced negatives of 7 by 9-1/8 inches or 9 by 9 inches as desired. While built as a precision instrument, it lacked provision for exactly collimating the film and the taking lens and thus did not meet requirements for a precision mapping camera.

Another development which was destined to have a major impact on both military mapping operations and R&D programs throughout World War II and for some years following was the adoption of the tri-metrogon method for aeronautical charting by the Air Corps early in 1941. This method employed three K-17 wide-angle reconnaissance cameras interconnected to make exposures simultaneously. With one camera pointing vertically downward and the other two inclined at an angle of 60° from the vertical on each side, horizon to horizon coverage was provided.

Since thi greatly reduced the amount of flying time, the use of the tri-metrogon system for photographic coverage of operation areas became the rule rather than the exception as the war progressed. Thus, it was necessary to develop specifications hastily, procure equipment, and train Engineer Topographic Units to compile reconnaissance maps with this photography. In February 1943, the Chief of Engineers directed the Engineer Board to develop methods and equipment to use the tri-metrogon photographs to the best advantage and, specifically, to make contouring possible. Only planimetric compilation at small scale was possible with the techniques and equipment then employed. Since it was realized that the large-scale battle map with its customary 50-foot contour interval was out of the question for the time being, the goal was set for aeronautical charts and strategic topographic map at approximately 1:500,000 with 1000-foot contours.

b. **Photomapping Accomplishments Through World War II.**

(1) **Development of Multiplex Equipment.** A number of intricate stereoscopic plotters were developed in Europe before and during World War I. After the war, these were slowly introduced into the United States. In the early 1930's, the Engineer Detachment obtained a Zeiss Aerocartograph, and early in 1935 it obtained the use of multiplex equipment owned by the Pittsburgh District for tests in connection with their investigations of the role of aerial photography in military mapping. Instruments such as the Aerocartograph or the Zeiss Stereoplanigraph were intended for use in the extension of ground control into unsurveyed areas. The multiplex was to be used for detail compilation. This idea, however, was gradually abandoned in favor of the use of the multiplex equipment for both extension of control and detail compilation even though aerotriangulation with the Aerocartograph or Stereoplanigraph was more accurate. The principal reason for using the multiplex equipment was that the Aerocartograph and similar instruments were expensive, nonportable, and time-consuming. Further, a domestic source of supply for this type of instrument would be both expensive and difficult to develop; whereas, by 1937, the Bausch and Lomb Optical Company had already begun manufacturing multiplex equipment in the United States on Corps of Engineers Specification T-851, dated 3 August 1936.

After extensive testing in the late 1930's, the multiplex was finally recommended for standardization by the Corps of Engineers in October 1939. It was noted that the sole source of supply was the Bausch and Lomb Company which controlled the American patent rights. However, this equipment was designed to use the photographs taken with the multiple-lens T3A camera. Both vertical and oblique projectors were developed.

When the T3A camera was replaced by the single-lens, wide-angle camera as the standard mapping camera in March 1940, it became necessary to provide a different type of multiplex equipment. Actually, the development of the wide-angle multiplex was already underway by the Bausch and Lomb Optical Company which was redesigning and improving the German equipment which had been imported for tests by the Engineer Detachment. The Corps of Engineers had on order 15 experimental projectors and all necessary supplemental equipment based on Corps of Engineers Specification T-896, dated 26 September 1938 (Fig. 1). The delivery of this equipment was not completed until May 1941 after the first large production order for 243 projectors and all necessary supplemental equipment (including four wide-angle reduction printers) had been placed with the Bausch and Lomb Optical Company.

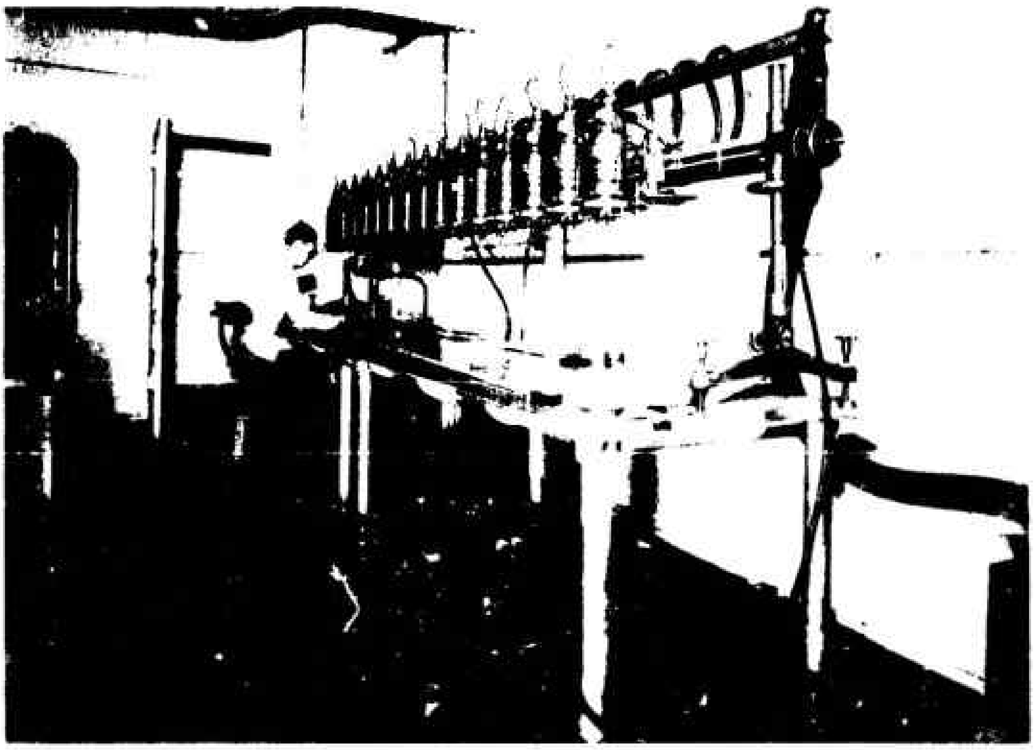

Fig. 1. Wide-angle multiplex equipment: the first 15 projectors manufactured by the Bausch and Lomb Optical Company set up for aerotriangulation tests (1941).

Engineering tests of the wide-angle multiplex equipment were conducted in 1941 to 1942 using photography at a 23,000-foot altitude with a K3B camera in the vicinity of Dayton, Ohio. With these photographs, the Engineer Detachment extended control for 70,000 yards and produced a complete battle map of the area.

Both in accuracy and speed, the wide-angle photography and plotting instruments proved themselves superior to the normal-angle types. In accuracy, the following results were indicated:

	35,000 Yards Extension	70,000 Yards Extension
Mean horizontal error	15 yards	19 yards
Mean error of distances	0.192%	0.275%
Mean error of azimuths	1.9 mils	3.1 mils
Mean vertical error	24 feet	28 feet

The Artillery requirements for position accuracy (no greater than 33 yards) were practically met in this test, but the requirement for elevation accuracy (no greater than 25 feet) was not quite satisfied. It was estimated that, with the wide-angle multiplex, the first map sheet should be available 6 days after photography and that, thereafter, 600 square miles per day could be produced by a Photomapping Company of the GHQ Engineer Topographic Battalion.

It should be noted that during the course of these investigations leading to the final development and adoption of the wide-angle multiplex, two other stereoscopic plotting instruments designed in the United States were investigated and rejected. One of these was the aerostereograph invented by Mr. Ernest R. Swanson, Junior Engineer, U.S. Engineer Office, St. Louis, Missouri which was investigated in 1936 and was rejected because it was more complex than the multiplex and would be costly to develop. The other was the stereoscopic plotter designed by Mr. O. M. Miller of the American Geographical Society and investigated in 1942. This instrument, the result of a 10-year project of the society, was designed for both vertical and oblique photography. It was rejected because it was in the initial stage of development, and, although it appeared somewhat simpler than comparable European instruments, the reasons for selection of the multiplex over this type of instrumentation were even more valid with a war in progress.

(2) The Stereocomparagraph. While the multiplex was suitable for base operation, a much smaller and more portable device was desired for the mobile mapping units. Such a device, the Stereocomparagraph, was invented by Captain Benjamin B. Talley of the Engineer Detachment and was reported to the Chief of Engineers

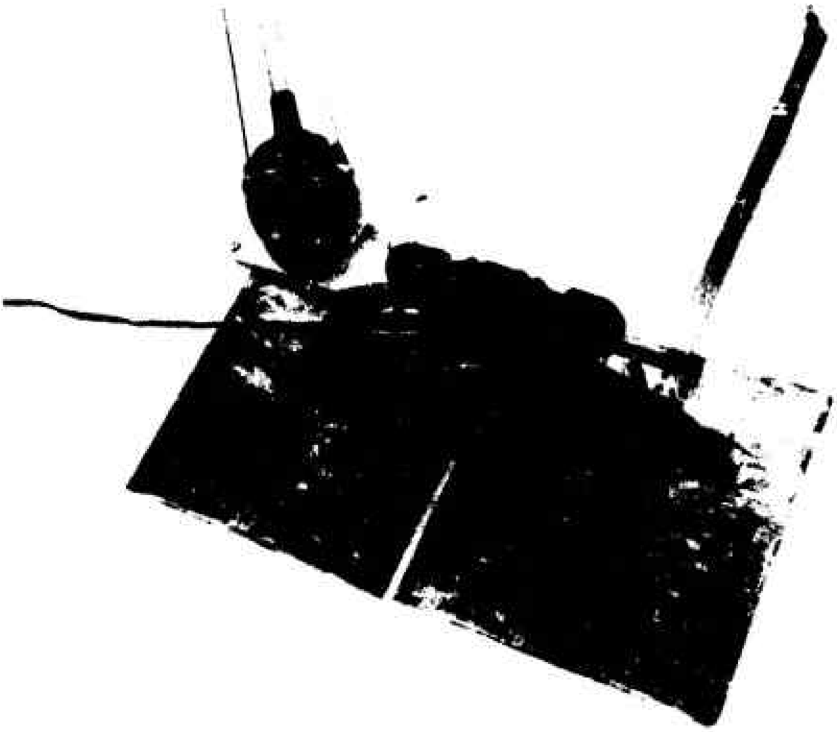

Fig. 2. The Stereocomparagraph.

in June 1936. As shown in Fig. 2, the Stereocomparagraph consisted essentially of a small mirror stereoscope, a parallax measuring micrometer with floating marks, and a pencil arm extension mounted on a parallel motion drafting machine. No provisions were made in the device to compensate for tilt or relief displacement in the photography. However, it was possible to sketch contours from near-vertical photography with a fair degree of accuracy. The device was service tested in 1937 and 1938 and was recommended for adoption as a standard item. However, final adoption and classification were delayed for several years while a Zeiss sketching stereoscope was investigated. In addition, the development by the 29th Engineers of a relief-compensating attachment devised by Captain Talley was anticipated. In the meantime, quantity procurement was initiated based on Specification T-1305 dated 9 May 1939. The item was finally standardized 27 March 1942 without the relief-compensating attachment.

(3) **Stereoscopes.** The development of stereoscopes for viewing overlapping aerial photographs received considerable attention in the 1930's as an accessory item to facilitate the interpretation of photographic detail. The only item in the inventory was a heavy, intricate, table model lens-prism stereoscope developed by the Keuffel and Esser Co. (Fig. 3). It had been standardized in 1932 and remained standard through

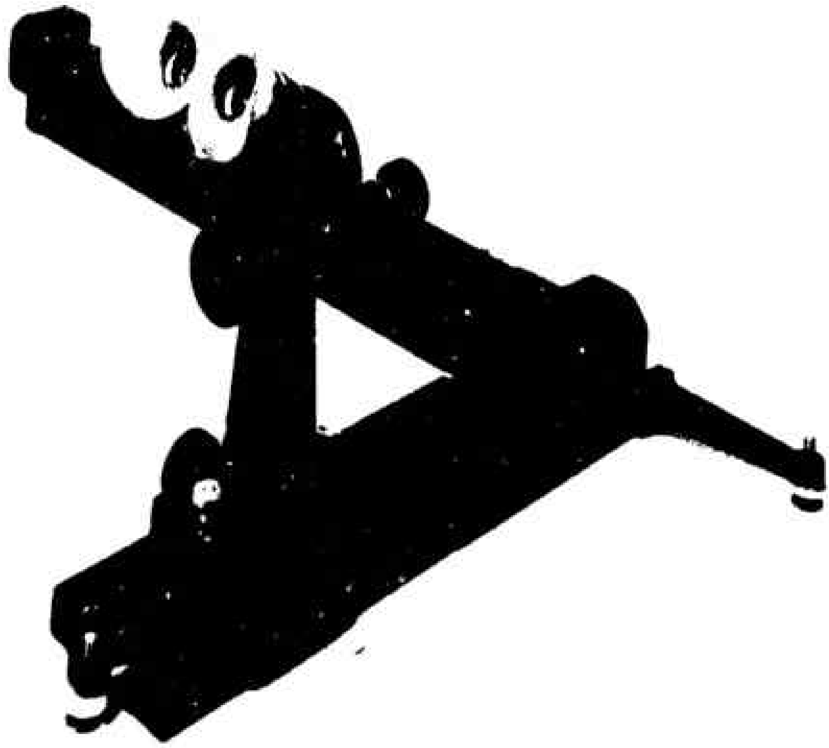

Fig. 3. Keuffel and Esser Lens-Prism Stereoscope.

World War II. However, it was not portable enough for issue to lower echelons and field units.

After several years of investigation, various cheap spectacle-type stereoscopes, anaglyphics spectacles, and mirror stereoscopes had been discarded from consideration. Finally, development was pursued on two parallel courses. The first approach was the development of a folding pocket stereoscope (Fig. 4) models of which were developed by Bausch and Lomb Optical Company. The other approach involved a magnifying mirror stereoscope (Fig. 5) which was produced by the Fairchild Aerial Camera Corporation. These items were finally perfected and adopted as standard articles in July 1940. The designs of both were based on German models.

(4) **Hasty Maps from Wide-Angle Photos.** The introduction of wide-angle photography in 1940 revived interest in other types of hasty maps that might satisfy needs of the Field Artillery for fire-control applications. During the years 1940 to 1944, various experiments and tests were conducted in preparation and use of contoured and uncontoured rectified photographs and controlled, semicontrolled, and

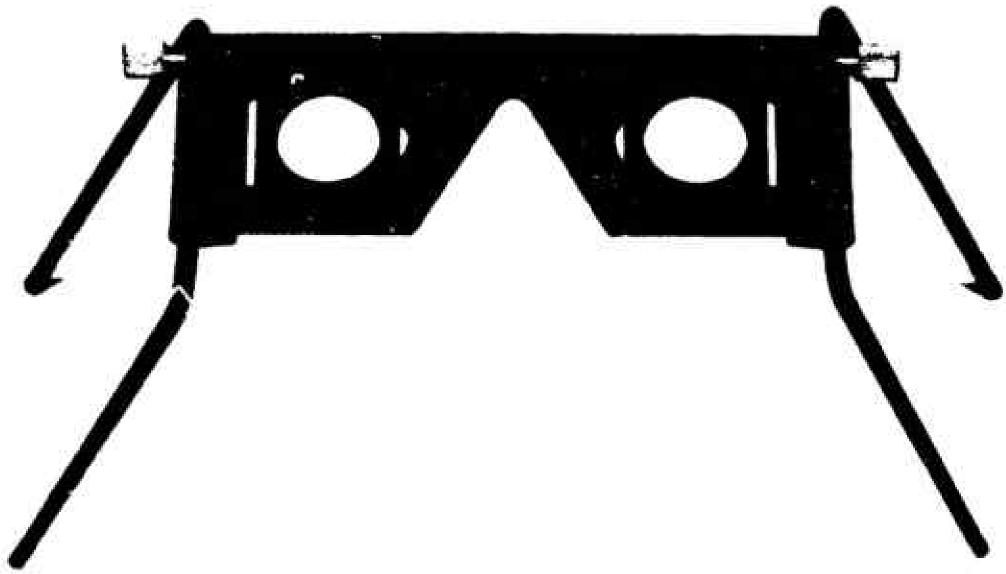

Fig. 4. Folding Pocket Stereoscope.

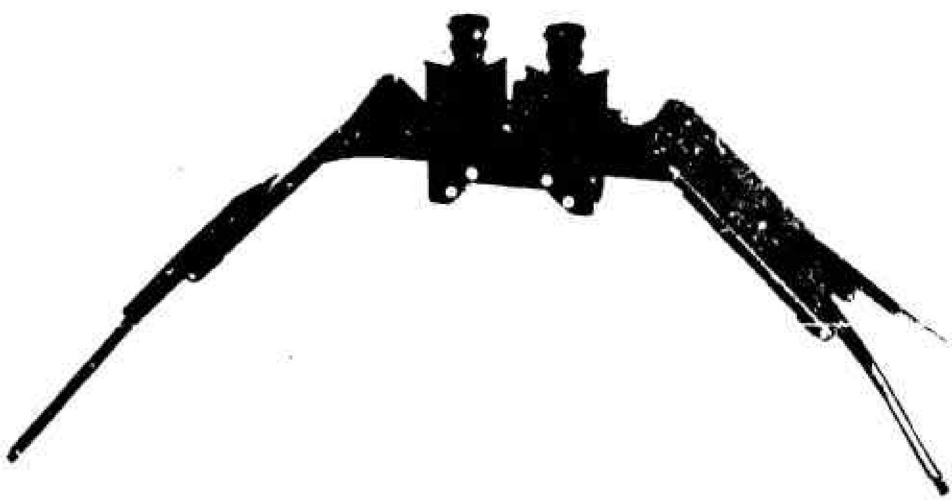

Fig. 5. Magnifying Mirror Stereoscope.

uncontrolled mosaics. The photo rectifications for these investigations were made with a Zeiss SEG I Rectifier procured from Germany by the Engineer Detachment.

None of these fully satisfied the Field Artillery accuracy requirements. The rectified photographs, contoured with the Stereocomparagraph, took too long to prepare and the Field Artillery School concluded that single photographs could best be used as contact prints. It took as long to prepare controlled mosaics (which included slotted templet control net expansion and photo rectification to the control net) as to prepare a complete topographic map. The semicontrolled mosaic assembled from contact prints did show some promise. The recommendations of the Engineer Board[15] resulting from these investigations were that mosaic should be further developed but should be considered only as an emergency expedient. The other possibilities of block plots (skeletonized planimetric maps) should be explored to provide a more suitable medium for fire control. Hasty maps were used successfully in the Mediterranean theater to satisfy Field Artillery demands for firing data because they were available well in advance of the complete battle map. They were prepared for the area north of Rome[16] by the 30th Engineer Topographic Battalion, GHQ, at the request of the 5th Army.

(5) **Mapping with Minimum Ground Control.** In July 1943, the Commanding General, Army Air Forces, directed the attention of the Chief of Engineers to SHORAN,[17] a device for determining horizontal positions over inaccessible areas. He requested that an officer be designated to represent the Chief of Engineers in the development of SHORAN. Major Gilbert G. Lorenz, Chief of the Aerial Photographic Branch, was authorized to cooperate with the Air Force in this program.

Preliminary tests were held in the vicinity of Boca Raton, Florida, from January to June 1944. These tests were so successful that the Engineer Board concluded that SHORAN was definitely applicable to the establishment of horizontal control for both multiplex mapping and mosaic making. The Board recommended immediate allotment of sufficient SHORAN equipment for mapping purposes pending further tests. SHORAN was found applicable to the navigation of precise flight lines as well as to position determination.

Development and test of the system continued in 1944 and 1945, and in August 1945 an Engineer Board Service Project (MPS 673) was set up to expedite the application of SHORAN to map control.

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15. "Mosaics for Field Artillery," Engineer Board Report 843, 21 July 1944.

16. "Use of Multiplex Equipment for Block Plots," Letter Report from Survey Directorate, Allied Force HQ, APO 512, US Army to OCE, 2 March 1944.

17. SHORAN is the acronym for Short Range Navigation. It was developed by Radio Corporation of America for the Air Force to facilitate bombing through overcast.

The Air Force and Corps of Engineers jointly conducted investigations into the establishment of vertical control for mapping with airborne instrumentation in 1942 and 1943. These experiments involved the use of a precise barometric altimeter to record the altitude above sea level and a radio altimeter to record the distance from the aircraft to the ground. Analysis of flight test data demonstrated that the method was suitable over flat or moderately rolling terrain but was not suitable over mountainous terrain except for small-scale aeronautical charting. The Aerial Photographic Branch found that in the tests conducted the errors were too great to permit the compilation of satisfactory large-scale maps. However, the report[18] did conclude that the radio altimeter could be used in the absence of horizontal control to more accurately determine the scale of a photograph, or photomap. The method was not recommended for use in making topographic maps. The radio altimeter was recommended for use in conjunction with the barometric altimeter for that purpose.

(6) Tri-Metrogon Equipment. With the sudden adoption of the tri-metrogon method for aeronautical charting early in 1941, it became clear that Engineer mapping units in the field would have to use high oblique photographs in mapping whether they wished to or not. In view of the urgency of the situation, the Engineer Board recommended the adoption of three instruments that had been developed by the United States Geological Survey: the vertical sketchmaster (Fig. 6), the oblique sketchmaster (Fig. 7), and the angulator. The angulator was designed to plot horizontal direction from the nadir to images on the oblique photographs. The sketchmasters were devices based on the camera lucida principle to plot planimetric detail from the photographs.

In February 1943, the Chief of Engineers directed the Engineer Board to develop methods and equipment to use the tri-metrogon photographs to the best possible advantage and, specifically, to make contouring possible. The first Engineer Board report on this investigation, submitted in October 1943,[19] discussed two approaches: (1) adapting the vertical, wide-angle multiplex projector so that it may be tilted to accommodate oblique photography, and (2) rectifying oblique photographs. A rectifier (Fig. 8) to investigate the latter approach was designed by Mapping Branch personnel and was constructed in the Engineer Board Shops.[20] It was designed to accommodate 9- by 18-inch photography at various tilts, since at that time the Air Force was experimenting with other multiple-camera arrangements including 9- by 18-inch photographs with 24-inch focal length lens.

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18. "Vertical Control for Aeronautical Charting and Mapping," Engineer Board Report 973, 27 February 1946.

19. "Improvement of Tri-Metrogon Plotting Equipment and Methods," Engineer Board Report, 19 October 1943.

20. "Rectifying Projection Camera Constructed at the Engineer Board," Engineer Board Report, 17 December 1943.

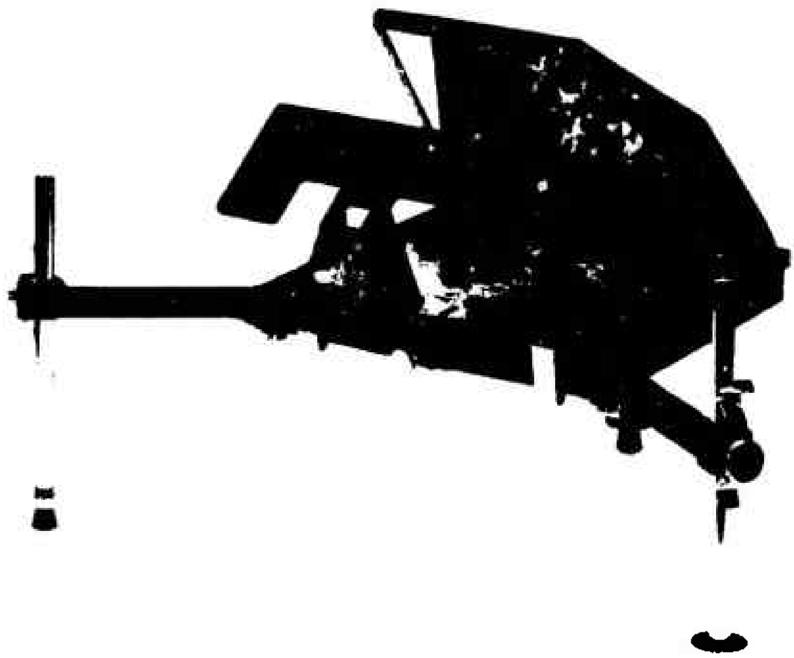

Fig. 6. Vertical Sketchmaster.

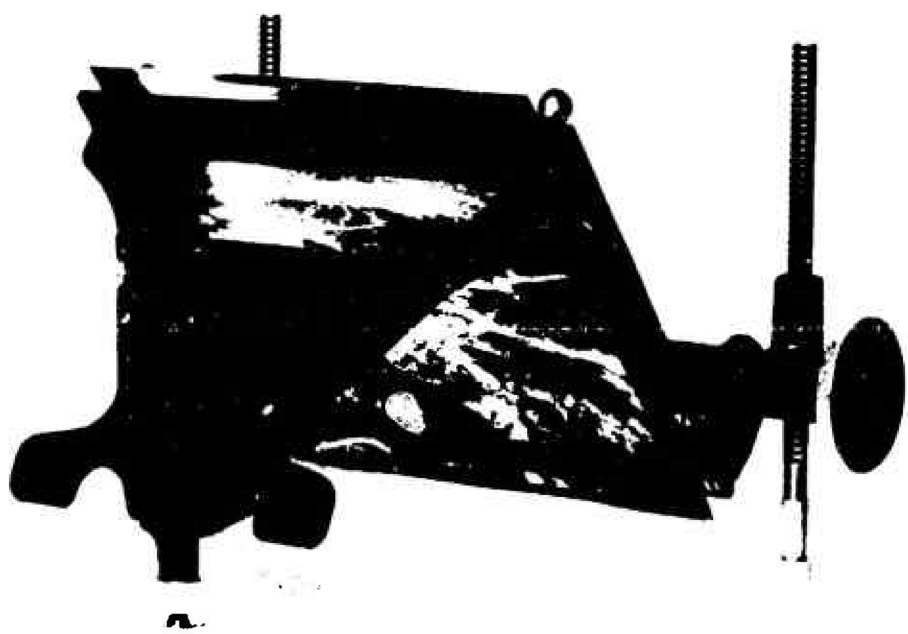

Fig. 7. Oblique Sketchmaster.

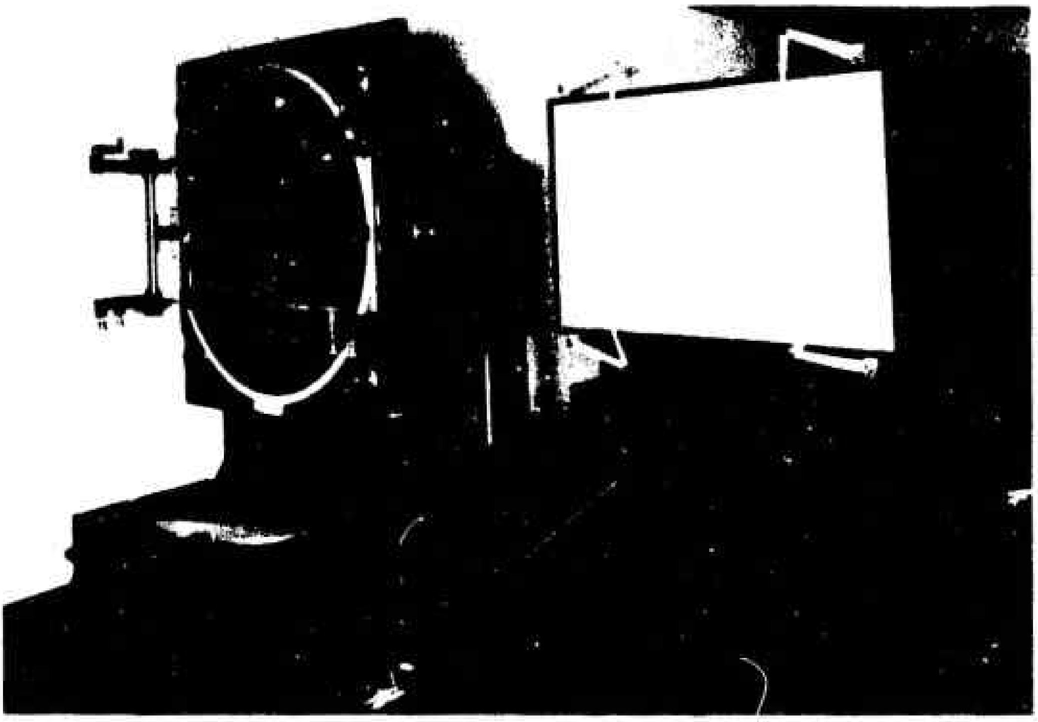

Fig. 8. Universal Rectifier designed by Engineer Board Mapping Branch personnel and fabricated in Engineer Board Shops (1943).

This instrumentation served as a valuable testbed for photo rectification and other studies. The rectifier was still being used occasionally in the early 1970's. In 1968, it was used by the Autometric Operation of the Raytheon Company to rectify photographs of Peru taken from a Gemini spacecraft. It was the only instrument that could be located that would accommodate the unusual tilts and formats. A small scale photomap of the entire country of Peru was prepared from the Gemini photographs.

Further investigation and test of the two approaches led to the adoption of an adjustable tilt bar which allowed vertical multiplex projectors to be used in oblique photo compilation (Fig. 9). To expedite introduction in the field, a number of these tilt bars were fabricated in the Engineer Board shops pending completion of specifications and drawings. Work with the rectified photographs[21] led to the establishment of project MP 488, Rectifying Camera, in March 1944 and also to the design of a new slot cutter to accommodate the rectified photos (Fig. 10). A pilot model of the slot cutter was also built in the Engineer Board shops.

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[21] "Military Mapping from Tri-Metrogon Aerial Photography Using Rectified Photographs," Engineer Board Report 830, 17 June 1944.

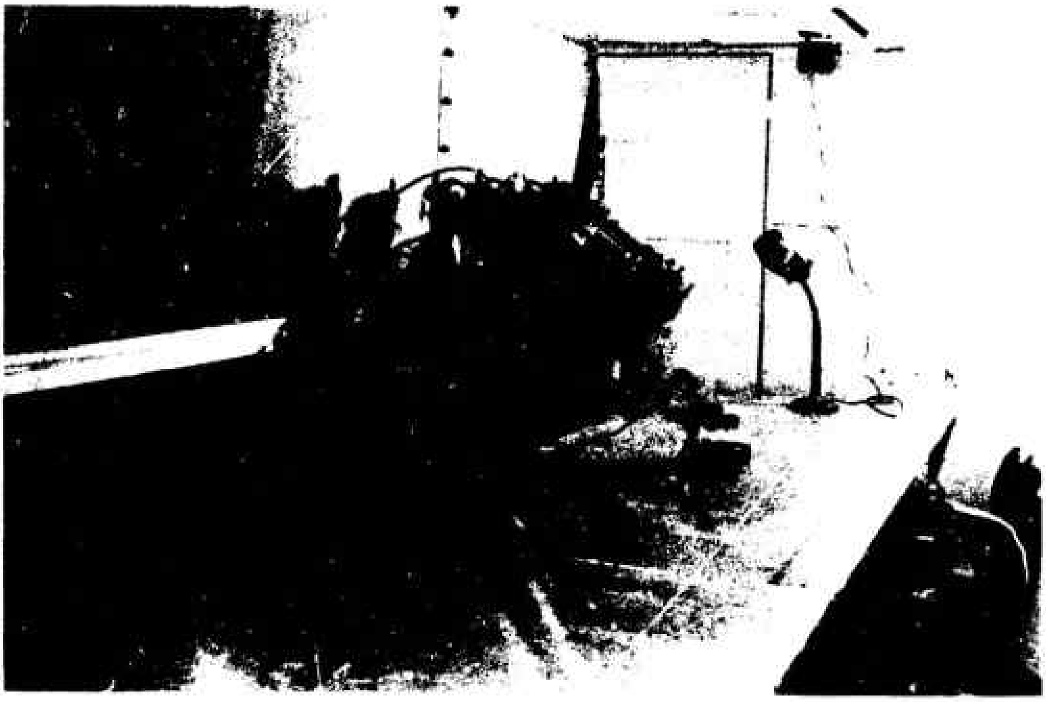

Fig. 9. Wide-Angle Mutliplex Projectors adapted for tri-metrogon oblique photo compilation with the adjustable tilt bar support.

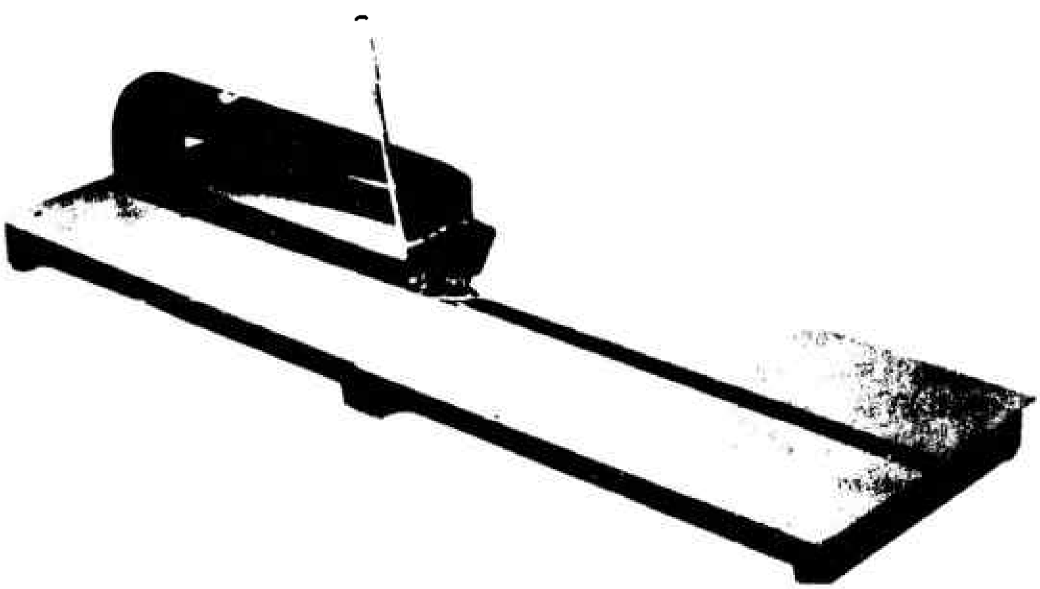

Fig. 10. Universal Slot Cutter designed to accommodate rectified tri-metrogon oblique photos as well as vertical photos.

The requirements were so urgent that experimental models of the rectifier were ordered from three firms in May and June 1944: Bausch and Lomb Optical Company, Aero Service Corporation, and Rutherford Machinery Corporation. In July 1944, a quotation was requested from Photogrammetric Instruments, Inc., Pasadena, California, for modification of a commercial rectifying printer known as the Fairchild Model RP1. Subsequently, 14 of these rectifiers, designated the RP2, were procured. They were delivered in May 1945. In the meantime, the development of the improved rectifier by the three companies lagged. The Aero Service Corporation model (Fig. 11) was delivered in October 1945 after the problem of a suitable lens was finally solved when the National Defense Research Committee supplied a "hypergon" lens of 4½-inch focal length. The Rutherford contract was cancelled in September 1945, and the Bausch and Lomb rectifier (Fig. 12) was not delivered until after the end of World War II.

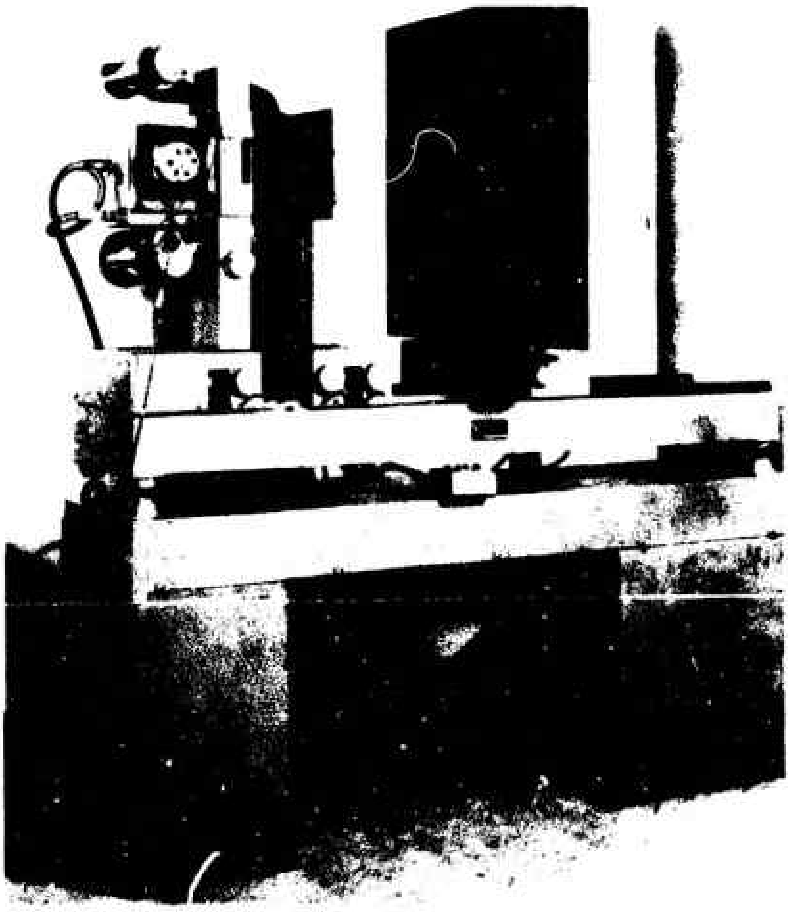

Fig. 11. High Oblique Rectifier—Aero Service Corporation Model.

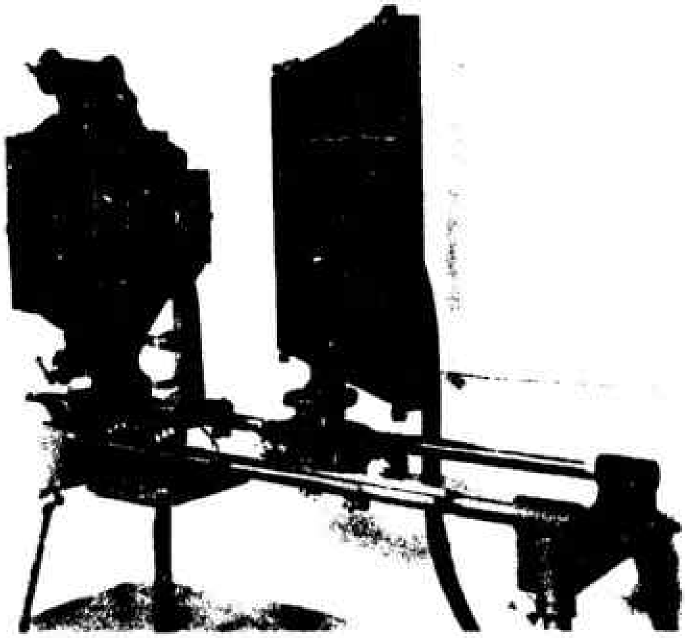

Fig. 12. High Oblique Rectifier–Bausch and Lomb Model.

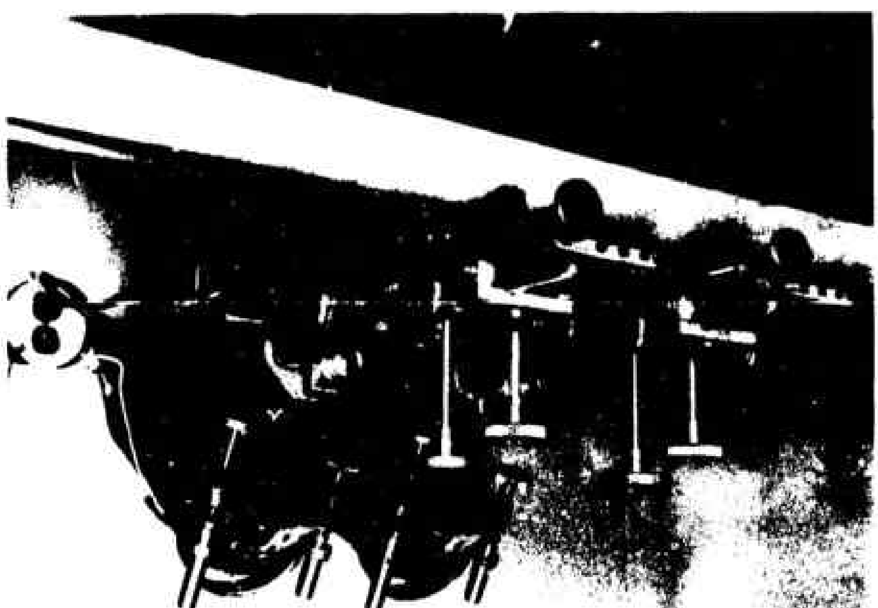

Fig. 13. High Oblique Multiplex Projector.

Another wartime development of tri-metrogon plotting equipment was a specially designed oblique multiplex projector (Fig. 13). Two experimental projectors were supplied by the Bausch and Lomb Optical Company in April 1945. These were submitted to the Engineer Board for test to determine if a development project should be set up. Such a project, MP593 High Oblique Multiplex Projector, was established in July 1945. Eighteen units with modifications found desirable in tests of the experimental models were ordered from Bausch and Lomb in January 1946.

(7) **Miscellaneous Investigations.** In addition to the more important work in the photomapping area outlined above, a number of miscellaneous investigations should be noted.

(a) **Vectographs.** The Vectograph process, developed by the Polaroid Corporation, Cambridge, Massachusetts, for viewing stereoscopic imagery by application of the principles of polarized light, was investigated in 1941 and 1942. The report[22] on these investigations concluded that vectographs were practicable but they required over twice as long to prepare as prints. Furthermore, the report noted that vectographs did not present as clear a view as prints viewed through a stereoscope. It was recommended that the use of vectographs be confined to training and that they not be adopted for issue.

(b) **Fairchild Detail Sketcher.** The Fairchild Detail Sketcher was a device based on the camera lucida principle designed for sketching from vertical photographs at either reduced or enlarged scale. It was not adopted because at the time it was preferable to use a vertical reflecting projector for this purpose.

(c) **Polaroid Projector.** The development of a polaroid stereoscopic projector to enable a group of persons to simultaneously view aerial photography stereoscopically was undertaken in 1941. Two experimental models were produced by Fairchild Aerial Surveys, Inc., Los Angeles, California. These proved to be inferior to a similar and less expensive device made by the Motion Picture Engineering Company, Detroit, Michigan. The project was dropped in 1942 when it appeared there was no longer a requirement.

(d) **Stable Cartographic Bases.** In 1941, at the instigation of the Engineer Detachment, the Eastman Kodak Company began work on a stable medium for cartographic purposes to replace their matte acetate sheeting. Although it had favorable dimensional stability characteristics, the sheeting was not satisfactory because it would only take soft pencil that had a tendency to smear. Eastman Kodak was successful in producing an acetate sheeting with improved surface characteristics in 1942.

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22. "Vectographs," Engineer Board Report 693, 10 July 1942.

The Engineer Board also investigated an acetate sheeting manufactured by the Celanese Celluloid Corporation, New York City, which proved to be too expansible for mapping purposes. The improved material of Eastman Kodak Company was adopted and procured in quantity during the remainder of the war. Shortly before the end of the war, vinylite sheeting was tested in comparison with the acetate sheeting and was found to give better results with both pencil and ink drafting. The Engineer Board recommended vinylite sheeting for adoption in November 1945.

(e) **Mapping from Relief Models.** Late in 1942, the Engineer Board investigated a method devised by Professor H. L. Cooke of Princeton University for making topographic maps from models carved in plaster of paris under multiplex projectors. It was concluded that the Cooke method required an expensive and bulky camera and special training in carving, and it was probably less accurate than the conventional method. The method was not recommended for military use.

(f) **Tangential Distortion.** During triangulation tests with the wide-angle multiplex equipment in 1941 and 1942, a rather large and consistent azimuth error in single-strip extension was noted. The cause for this was traced to a tangential distortion in both the mapping camera and in the multiplex reduction printer. This work was the basis for the inclusion of tangential distortion limitations in mapping camera lens specifications and also for the development of parallelism tolerances for camera filters and windows.

(g) **12-inch Focal Length Wide-Angle Camera.** In 1939, the Chief of the Army Air Corps called attention to a camera recently perfected by Fairchild Aerial Surveys, Inc., Los Angeles, California, for its own use. It was fitted with a 12-inch focal length, wide-angle metrogon lens. An experimental camera designated the XT-6 was procured by the Air Corps at the urging of the Chief of Engineers.

The Corps of Engineers procured a special reduction printer from the Bausch and Lomb Optical Company for preparation of multiplex diapositives (Fig. 14).

In September 1940, after an experimental T5 camera (9x9 inch, 6-inch focal length) had been delivered to the Air Corps, comparative tests were made by the Engineer Detachment. The tests demonstrated that photographs taken with the XT-6 camera were of better quality than enlargements of T5 photographs but not sufficiently better to justify the continued procurement of such a large camera. Accordingly, the Chief of Engineers recommended that the development be suspended.

(h) **Portable Plotters.** In the period 1940 to 1945, several devices were investigated for possible replacement of the stereocomparagraph for contour

Fig. 14. Experimental Multiplex Reduction Printer for 12-inch focal length, 18- by 18-inch format photography with metrogon lens.

mapping by those organizations not equipped with the multiplex. The first of these was the Abrams Contour Finder—a device similar in principle to the stereocomparagraph. However, it was not suitable for use with 9- by 9-inch photographs and was rejected. Other devices investigated were the KEK plotter (Fig. 15), designed by Messrs Jasper E. King, John W. Elliot, and Philip B. Kail, investigated in 1941; the SCS plotter, designed by Mr. Charles Cook of the Soil Conservation Service, investigated in 1943 and early 1944; an improved model of the KEK plotter investigated in 1944; an improved model of the SCS Plotter called the stereotopograph ordered from the Fairchild Aviation Corporation in 1944 but not delivered until January 1946; and the stereograph, invented by Mr. Andrew Bendixen of the Army Map Service. All of these devices employed a mirror stereoscope arrangement for viewing and compiling from contact prints. They differed in the manner in which the floating marks were introduced in the stereoscopic model and the means provided for compensation for tilt in the photography.

The investigation of the Bendixen Stereograph was completed in 1945. The Bendixen Stereograph was rejected because two principles of stereoscopic vision were violated, thereby causing eyestrain. Investigations of the KEK Plotter and the stereotopograph were still not completed at the end of the war.

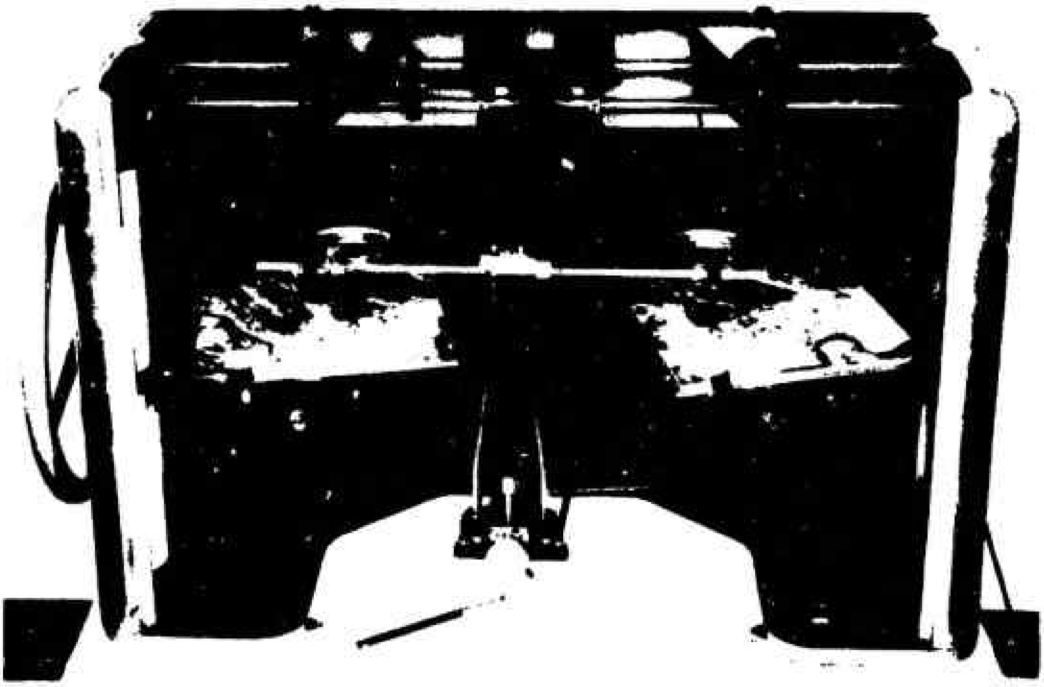

Fig. 15. The KEK Plotter manufactured by Philip B. Kail Associates, Denver, Colorado.

(i) **Multiplex Inspection.** Throughout World War II, the responsibility for the factory inspection of all items of multiplex equipment was vested in the Engineer Detachment and later the Mapping Branch of the Engineer Board because of their special nature. This required temporary duty of Corps of Engineers personnel at the Bausch and Lomb Optical Company before each shipment. Later, personnel of the Army Map Service were trained to perform the factory inspection, and they inspected equipment procured for the Army Map Service.

(j) **Camera Calibration.** After adoption of the single-lens, wide-angle camera and during the early part of World War II, the calibration of mapping cameras was performed by the Engineer Detachment using a field range set up at Wright Field. At first, this range was the guardrail on an earth-filled dam near Wright Field. Later, a camera calibration range was set up on the base with an array of specially designed targets along one of the boundary fences of the field.

This was the principal calibration facility for the military until a multicollimator facility was built at the Fairchild Camera and Instrument Corporation, Long Island, New York. Up to that time, camera calibrations for both civil and military agencies were made on request by the National Bureau of Standards.

c. **Map Reproduction Accomplishments Through World War II.**

(1) **General.** In World War I, the map reproduction equipment of the Army was rather limited. As late as 1928, when development work began in earnest, the items in use included only a blueprinting set, a small hectograph duplicator, slow speed lithographic apparatus with a flatbed hand press, and an experimental mobile reproduction train containing elaborate and bulky letterpress equipment mounted on Mack trucks. Some consideration was given at the time to mounting the latter in railroad cars.

Work in the late 1920's and well into the 1930's was directed primarily toward investigations of duplicating processes to provide something better than the blueprinting equipment and the hectograph duplicator for issue at the regiment and division levels. The ammonia process (ozalid), the Bruning black and white process, the bromide process, the mimeograph, the spirit duplicator, and the gelatin roll duplicator were investigated. In the mid-1930's, the problem of reproducing photomaps in quantity gained considerable attention. Both photographic and lithographic processes were investigated; the lithographic process had been adopted as more suitable for map reproduction in the Army than the other basic printing techniques.

By the eve of World War II, the Corps of Engineers was not prepared for the unprecedented demand for maps which was ahead and which required the supplementation of the basic mapping plant, the Army Map Service, by a large number of field Army units. (Army Map Service operations were supplemented during the war by 4 GHQ Topographic Battalions, 12 Army Topographic Battalions, 27 Corps Topographic Companies, and 33 Engineer Air Force Companies.) A crash program of development and equipment procurement and assembly was therefore required, and the program was placed under the cognizance of the Engineer Board.

(2) **Development of the Corps Company Mobile Reproduction Plant.** A mobile reproduction plant for use at the Corps level had been developed in 1937 but had not been service tested. The plant consisted of a tractor-truck and 2-ton trailer (Fig. 16) fitted with two multilith presses (Models 2066 and 40), a plate whirler, a vacuum printing frame, an arc lamp, and other accessories, and a 1½-ton truck fitted with a 5-kva generator set, drafting and surveying equipment, a black and white developing machine, and a Model LW New Process Duplicator. After a series of service tests, modification, and changes in components, the set eventually evolved in 1941 into an assemblage of equipment mounted in a single, vantype semitrailer and a 5-kw generator set. The following items of equipment were included:

(a) 10 inch by 10 inch vertical projection camera
(b) Temperature-controlled photographic processing tray
(c) 133-line glass halftone sensor

(d) 300-line contact halftone sensor
(e) Table-mounted plate whirler
(f) Wall-mounted vacuum printing frame
(g) Electronic arc lamp
(h) 20 inch by 22½ inch offset press
(i) Gasoline heater
(j) Air conditioning unit
(k) Pressure water system.

This mobile plant was classified limited standard by the Services of Supply, and the Corps of Engineers was requested to redesign it immediately for truck mounting. This was accomplished eventually by using truck-mounted equipment sections developed for the Army Battalion Map Reproduction Train for the Corps Company Mobile Plant Requirement.

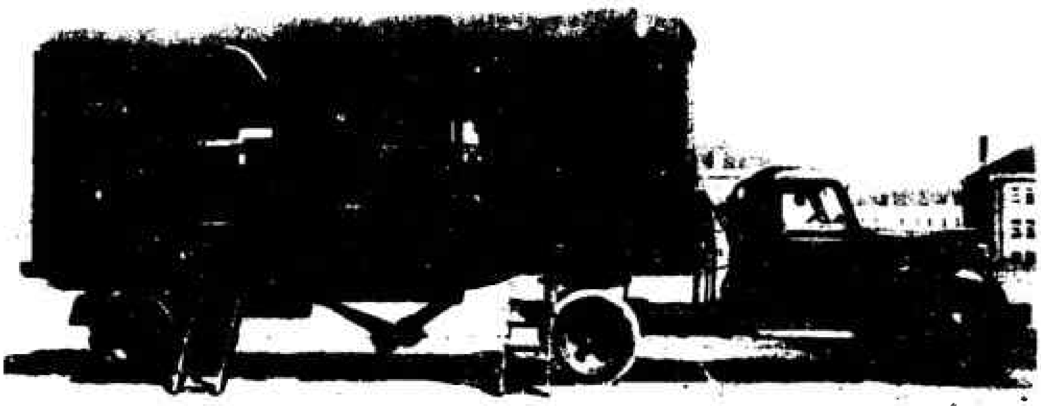

Fig. 16. Pre World War II map reproduction trailer.

(3) **Development of the Army Topographic Battalion Mobile Reproduction Train.** Although a series of studies and investigations of what should be done about a mobile map reproduction train for the Army Topographic Battalion had been made by the Board of Engineer Equipment, the Engineer Reproduction Plant, and the Engineer Board starting in about 1923, it was not until June 1940 that the specific problem of redesigning the mobile train was seriously attacked. Before this, individual items of lithographic equipment had been developed for the GHQ Battalion and the Corps Company, and valuable experience had been gained by the design of the Corps Company mobile plant.

On 5 June 1940, project SP319, Mobile Map Reproduction Train, Topographic Battalion, was assigned to the Engineer Board by the Chief of Engineers,

and the Chief of Engineers requested a list of equipment and an estimate of costs as soon as possible. The Engineer Board replied promptly to this request on 22 June 1940 by describing an eight-trailer train which was estimated to cost $125,000 and would be equipped with:

(a) Trailers 1, 2, and 3 – 22-inch by 29-inch Webendorfer "Big Chief" offset press.

(b) Trailer 4 – One vacuum printing frame, one 25-ampere, 110-volt arc lamp, and one vertical plate whirler.

(c) Trailer 5 – One 24-inch by 30-inch copying camera, one 120-line and one 133-line glass screen.

(d) Trailer 6 – One 10-inch by 10-inch contact printer and processing equipment.

(e) Trailer 7 – One or two plate grainers.

(f) Trailer 8 – Laboratory equipment and supplies.

In September 1940, a semitrailer train was ordered from the Fruehauf Trailer Company. The installed equipment was ordered separately and shipped to Detroit where it was assembled under Engineer Board supervision. The first completed reproduction train was delivered to the 30th Engineer Topographic Battalion at Fort Belvoir, Virginia, in April 1941 (Fig. 17).

Fig. 17. Map reproduction train developed in World War II.

Despite the magnitude of the job and the speed with which it was accomplished, this experimental model proved satisfactory with one exception: movement of the grainer trailer during operations prevented that machine from functioning properly. This was readily corrected by providing portable supports for the trailer.

A second train was ordered in December 1941 incorporating several changes including the installation of the newly developed 20-inch by 22.5-inch lightweight Harris Press and facilities for using the newly developed 300-line contact screen process. Shortly after this procurement in March 1942, the Engineer Board proposed to redesign the train to use van-type trucks instead of semitrailers of seven different types:

(a) Four press trucks, 4-ton.
(b) One camera truck, 4-ton.
(c) One plate-process truck, 2.5-ton.
(d) One plate-grainer truck, 2.5-ton.
(e) One laboratory truck, 2.5-ton.
(f) One photographic truck, 2.5-ton.
(g) One map layout truck, 2.5-ton.

The first order for the new type Army Battalion mobile train was placed with Peter Wendel and Sons, Inc., Irvington, New Jersey, in June 1942. The first complete truck-mounted reproduction trains were delivered to the field in January 1943 (Fig. 18).

Fig. 18. Map reproduction unit with van type body on 2.5-ton truck chassis – laboratory section – developed in World War II.

(4) **Portable Task Force Equipment.** As World War II progressed, task forces of divisional size would be detached at times from larger units. It was desirable for these forces to provide their own maps, especially those that were reproductions of aerial photographs. The Engineer Board proposed lithographic printing to meet this need, and in November 1942 it began to develop a portable copying camera and plate processing set to accomp ny the Model 40 Multilith. The set weighed only 168 pounds. Eight manufacturers were contacted, and by March 1943 three of them had agreed to construct experimental models. Project MP404 was therefore established. In the meantime, the requirement was so urgent that the Chief of Engineers procu ed 20 Beattie field process cameras and accessories, manufactured by the Progressive Promotions Company, Summit, New Jersey. The Model 221 Davidson duplicator, which weighed 726 pou ds, was supplied with this set. This equipment proved unsatisfactory in the field, largely because it could not withstand field usage.

Both the Huebner Laboratories, New York City, and the Rutherford Machinery Company Division of the General Printing Ink Corporation, New York City, delivered experimental models to the Engineer Board in April 1943. At approximately the same time, project approval was obtained from the Army Service Forces. The experimental models were promptly tested by the Engineer Board and returned to the manufacturers for some suggested modifications. During July, the third model manufactured by American Type Founders, Inc., Elizabeth, New Jersey, was delivered to the Engineer Board. By September, three sets of equipment, including modified Huebner and Rutherford sets, were submitted to the 665th Engineer Topographic Company Corps for service test (Figs. 19, 20, and 21).

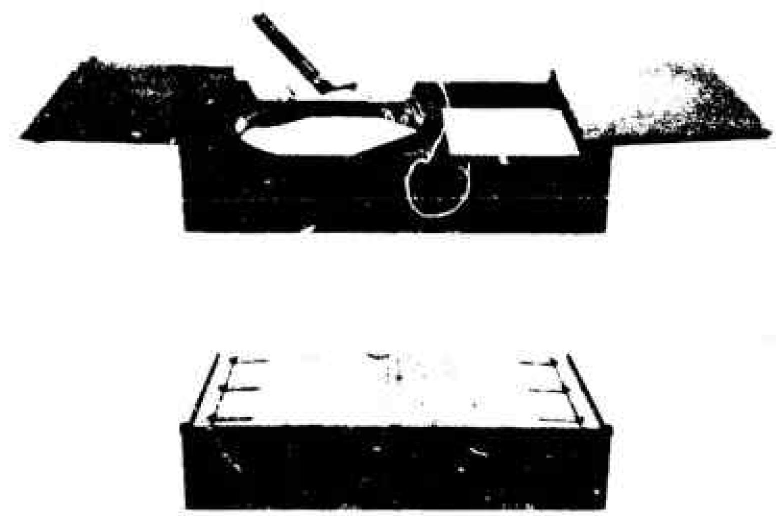

Fig. 19. Portable task force equipment developed in World War II, plate whirler and processor.

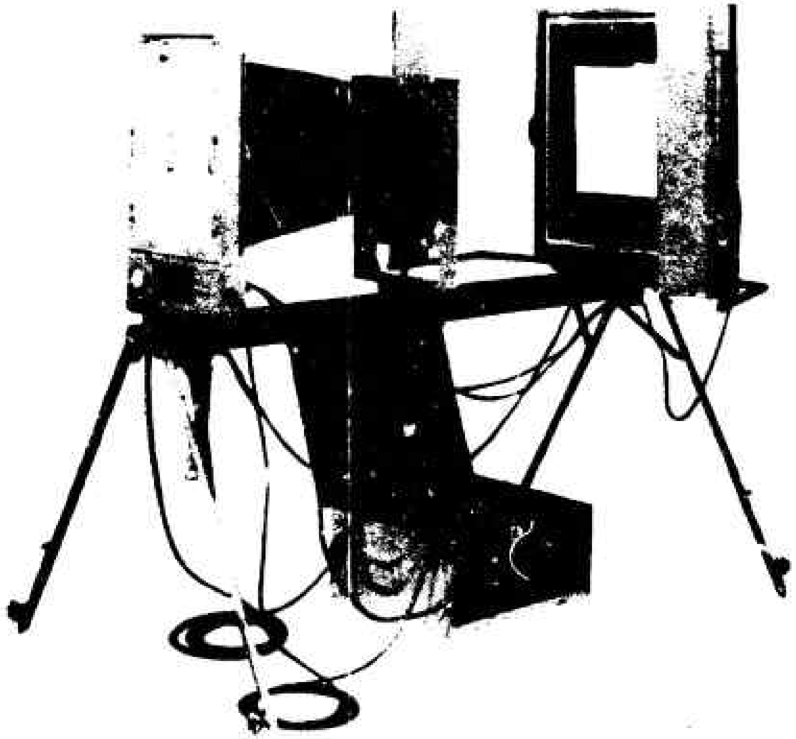

Fig. 20. Portable task force equipment developed in World War II, process camera.

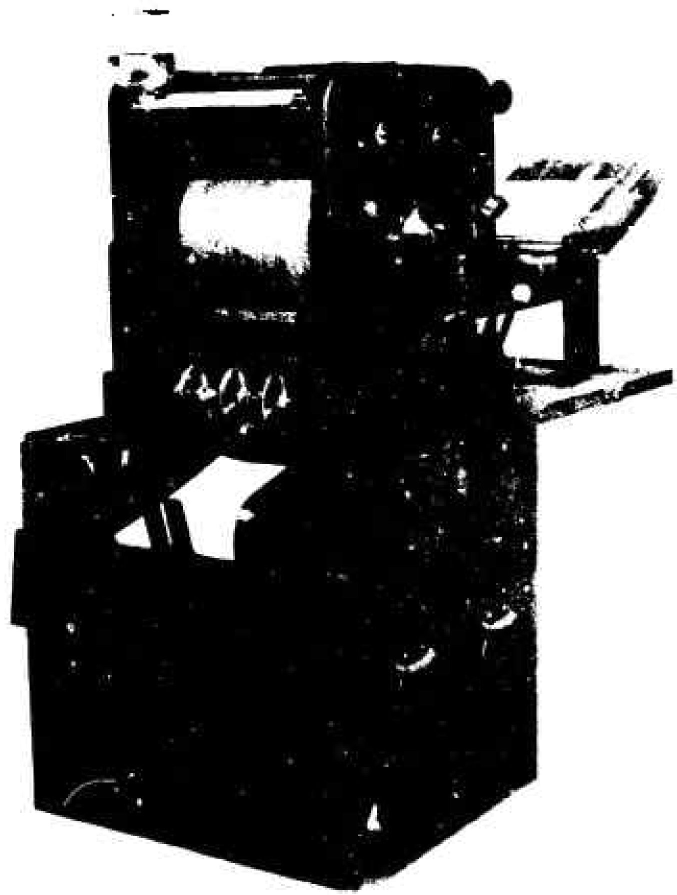

Fig. 21. Portable task force equipment developed in World War II – Davidson duplicator.

The model 40 multilith was found unsatisfactory in these tests. Of the three portable cameras and plate process sets, the one manufactured by the Rutherford Machinery Company was the most satisfactory, primarily because it was lighter and more portable and required the least modification. The set was finally classified standard in May 1944, with a modified model 221 Davidson duplicator that had been employed in tests by the Engineer Board.

The project was closed in June 1944 only about 14 months after its approval by the Army Service Forces and barely 18 months after initial contacts with manufacturers regarding equipment development.

(5) **Lithographic Press Development.** Lithographic press development through World War II consisted primarily of investigating and testing lithographic press equipment on the commercial market for specific field Army applications. In some instances, the equipment was modified to better suit Army needs. In 1934, several multilith machines manufactured by the Addressograph-Multigraph Corporation, Cleveland, Ohio, were tested for application at the regiment or division levels, and of these the model 200 was favored and recommended for service test. This was a small, hand-operated machine giving a 9-inch by 12½-inch impression. Although the machine proved generally acceptable in service test in 1936, the Engineer Board recommended its rejection in October 1937 because a larger multilith, electrically operated and capable of printing a 12-inch by 19-inch map, was then being tested.

The larger press, originally model 216 and later model 2066, had been obtained in February 1936 and was slightly modified in the Engineer Board shops. It weighed 1200 pounds and produced 4000 copies per hour. This press, together with another smaller multilith machine, the model 40, was included in the original trailer-mounted Corps Company map reproduction plant developed for service testing in 1937. (The model 40 was also considered later for the Portable Task Force Reproduction Set.)

Later, the Davidson model 221 duplicator was tested by the Engineer Board. It was ultimately adopted in 1944 in lieu of the model 40 multilith for the Portable Task Force Equipment.

Although the Model 2066 Multilith had been successfully service tested twice, it was still not completely satisfactory. Heavier offset presses were simpler to operate and gave better results particularly for fine-screen halftones. This was becoming an overriding consideration in the late 1930's with the introduction of the photomaps.

In August 1939, the 6th Engineer Topographic Battalion suggested the replacement of the Model 2066 Multilith with a newly developed 17-inch by 22-inch press manufactured by the Harris Seybold Potter Company, Cleveland, Ohio. This

suggestion was rejected by the Engineer Board on the basis that the press, which weighed 4750 pounds, was too heavy for mobile units. By mid-1941, however, the manufacturer had redesigned the press for Engineer Corps Company uses. The new machine, designated the model LTE, weighed only 2264 pounds. A later change in design enabled the press to accommodate a 20-inch by 22½-inch sheet (Fig. 22).

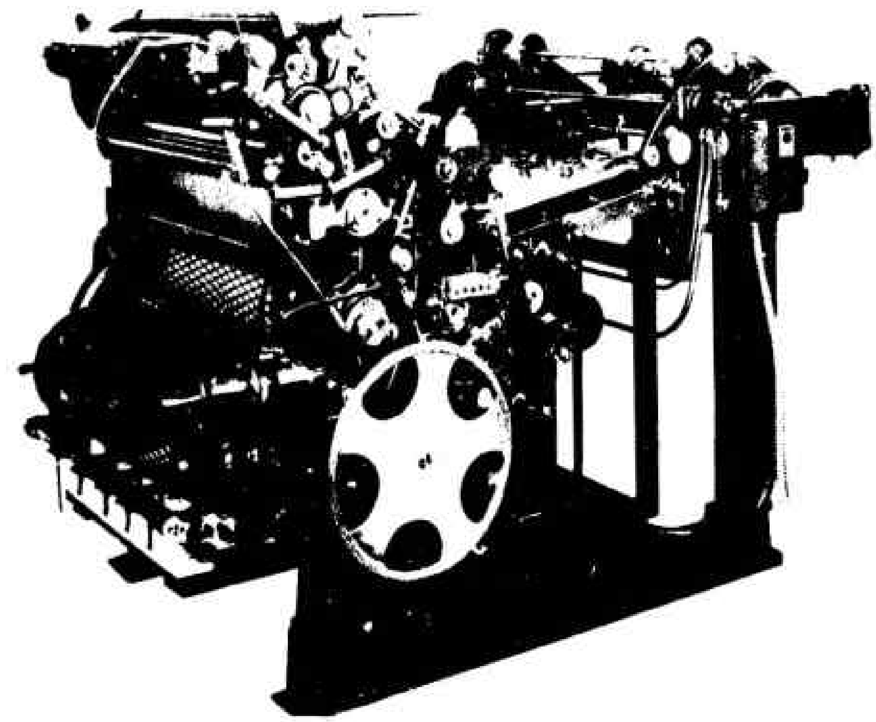

Fig. 22. The Model LTE Harris Press—20 by 22½ inch sheet size.

After a representative of the Engineer Board examined this press at the factory, it was recommended for immediate procurement. The first order for 38 units was placed in October 1941. The pilot model was delivered in November, and a number of changes were made before the production models were fabricated. The model LTE Harris press was standardized on 30 July 1942.

In September 1944, the Army Air Forces called a conference in Washington, D. C., to discuss the application of the portable task force equipment to Air Force needs. The conference was attended by representatives of the Air Forces; the Office, Chief of Engineers; the Engineer Board; the Army Map Service; the Office, Quartermaster General; and G-2 section of the War Department General Staff. It was decided at this conference that all future development and procurement of map

reproduction equipment should be of items readily transported by air in standard cargo planes. The Army Air Forces Board was directed to determine the military requirements for reproduction equipment. The board filed its report on 28 November 1944[23] and among other things recommended that the Army Air Forces and the Corps of Engineers open a joint development project on an air-portable reproduction unit consisting of a 22-inch by 29-inch press, 24-inch by 30-inch copying camera, and related equipment. This report was finally approved by the Commanding General, Army Air Forces, on 30 May 1945; but, in the meantime, the Engineer Board had been working on a plan for the proposed joint development. It was decided that the most feasible approach was to divide the project into two parts: one on the airborne camera and plate processing equipment; and the other on the airborne press. Approval from the Army Service Forces was obtained in July 1945 after coordination with the Army Air Forces and Army Ground Forces. Projects MP 580, Airborne Camera and Plate Process Equipment, and MP 581, Airborne Press, Lithographic Offset were approved on 18 July 1945.

Development work on these items was delayed when the war ended. In August 1945, the Engineer Board ordered an experimental model airborne press from the Webendorfer-Wills Division, American Type Founders, Inc., Mt. Vernon, New York. Production was delayed by plant reconversions. Also, in August 1945, the Litho Equipment and Supply Company of Chicago, Illinois, submitted a promising bid for the airborne camera, but negotiation of the contract was held up by plant reconversion and eventually lapsed. In March 1946, the Zarkin Machine Company, New York City, contracted to build the experimental camera and 3 months later agreed to supply the plate-processing equipment. The airborne press was still not in production at this time.

(6) Copy Camera Development. The service tests of the original Corps Company mobile reproduction plant in 1938 and 1939 disclosed the need for a mobile copying camera. In November 1939, the Engineer Board requested authority to open Project SP210A for a mobile camera capable of producing negatives with a maximum size of 24 inches by 24 inches. On 12 January 1940, a development contract was awarded to the Rutherford Machinery Company Division, General Printing Ink Corporation. The experimental Rutherford camera was delivered in March 1941.

In the meantime, the Engineer Board forwarded a draft specification for the 24-inch by 24-inch camera early in March 1940 and the Chief of Engineers immediately issued invitation for bids so that mobile cameras could be supplied to the 29th and the 30th Engineers in time for Army maneuvers in August. As a result of this invitation, a contract for three cameras was awarded to the Lanston Monotype Machine Company, Philadelphia, Pennsylvania. In July and August 1940, the Engineer Board

23. "Equipment, Reproduction, Portable, for Task Forces (Engineer Board Model) and Requirements for Reproduction Facilities for AAF Tactical Operations," AAF Bd. Report, 28 November 1944.

fitted out and shipped four trailer-mounted copying cameras, two to the 30th Engineers, and one each to the 29th and 64th Engineers. After brief tests in the field, quantity procurement of the 24-inch by 24-inch camera was initiated in December 1940 by an order to the Lanston Monotype Machine Company. The camera was finally standardized on 30 July 1942.

Fig. 23. Huebner vertical projection camera, 10 by 10 inch.

The 10-inch by 10-[illegible]rtical projection camera (Fig. 23) was also developed during the war to provide a camera unit within the combination semi-trailer reproduction plant developed for the Corps Company so that a separate vehicle as required for the 24-inch by 24-inch camera (Fig. 24) would not be necessary. An experimental model of this camera was ordered from Huebner Laboratories, New York City, in January 1942 and was delivered to the Engineer Board in the same month. A

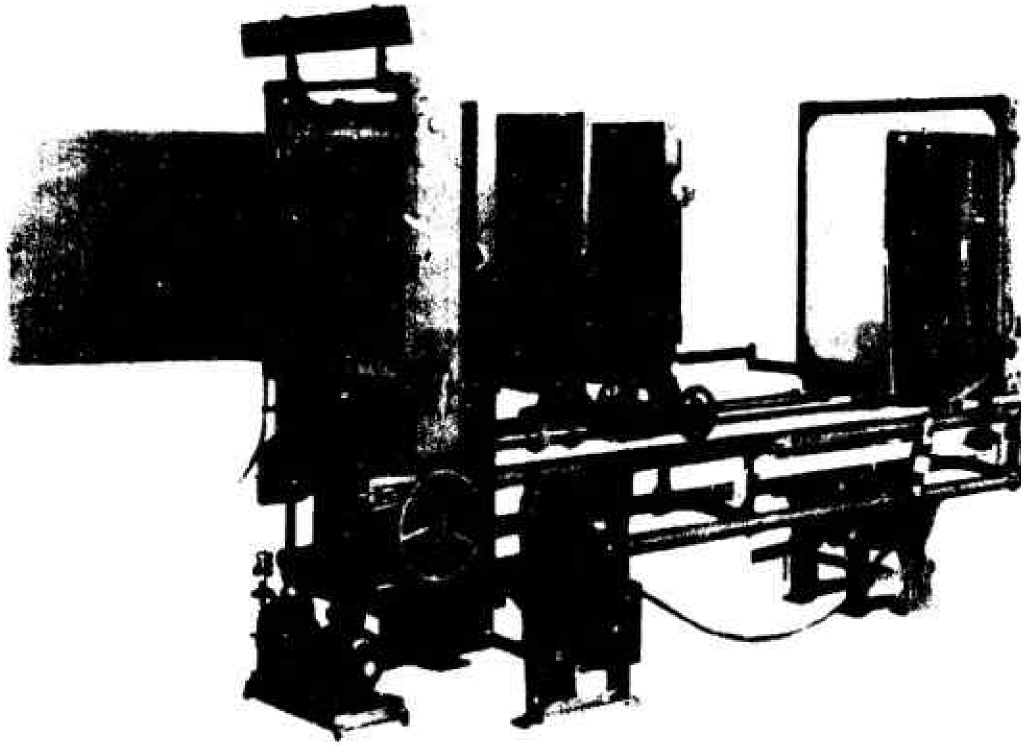

Fig. 24. Mobile process camera—24 by 24 inch.

few corrections were made after tests by the Engineer Board, and 30 production units were ordered for the first lot of Corps Company Reproduction Plants.

The Services of Supply would not classify the trailer-mounted reproduction sets as standard, and in October 1942, asked that they be redesigned for truck mounting. It proved preferable to provide a separate truck with the 24-inch by 24 inch camera rather than to include the vertical camera in the truck-mounted plate process sections.

(7) Rapid Photographic Printers. In the late 1930's and early 1940's, the quality of lithographed reproduction of photomaps was so low that field organizations always preferred contact prints. Therefore, in 1939, the Engineer Board directed its efforts toward development of rapid photographic printers and processors to reproduce the T3A composite photographs which were then the accepted type of hasty photomaps.

Initially, the Engineer Board was directed to develop two types of contact printers: a mobile machine for reproducing prints up to 20 inches by 24 inches

in size at the rate of at least 600 per hour, and a larger machine for base plant use. This was later modified at the request of the Engineer Board to the development of a semi-permanent type capable of handling prints up to 20 inches by 24 inches and a truck- or trailer-mounted unit for prints up to 10 inches by 15 inches.

Work on the two types proceeded simultaneously, and Mr. Garraway of the Garraway Company of Rutherford, New Jersey, was engaged to design the equipment and to supervise assembly of the experimental models at Fort Belvoir. Designs were completed by February 1940. The larger printer was assembled by September, and the mobile unit was completed in November.

Neither of these developments was satisfactory. The large unit was too bulky for truck mounting, and in November 1942 it was suggested that it be transferred to Army Map Service. Since the Army Map Service did not want it, the Chief of Engineers authorized its salvage in April 1943. The mobile unit was installed in a van-type semitrailer and was shipped to the 64th Engineers for service test. On 27 June 1941, the 64th Engineers issued an adverse report noting that the printer should not be added to the reproduction plant of the Corps Company because it had certain mechanical defects and the printing area was limited to 10 inches by 15 inches which was too small to effectively use the new wide-angle photographs.

In November 1940 after the introduction of wide-angle photography, work had begun on a mobile machine for enlarging the 9-inch by 9-inch negative to as much as 20 inches by 20 inches, with a production rate of 600 per hour. The purpose of the enlargement was to produce a photomap at a scale of 1:20,000 from photographs taken with the 6-inch metrogon lens. In those days, the photographs were usually at a scale of about 1:40,000.

The experimental model of this machine was completed in February 1942. It was mounted in a van-type semitrailer and shipped to the 665th Engineer Topographic Battalion for service test in October 1942 (Fig. 25).

The trailer-mounted Garraway projection printer was tested extensively in the summer of 1943 during the Second Army maneuvers in Tennessee. In August 1943, the 665th Engineers reported that it would be a valuable addition to the mobile reproduction equipment with certain changes, including provision for production of prints of the same size as the original negative and truck mounting for better mobility.

The unit in a truck-mounted version was standardized in March 1944. The experimental model was eventually shipped to the 660th Engineer Topographic Battalion, GHQ, in the European Theater. In June 1944, this unit suggested the addition of a contact-printing attachment. This was accomplished by a change in

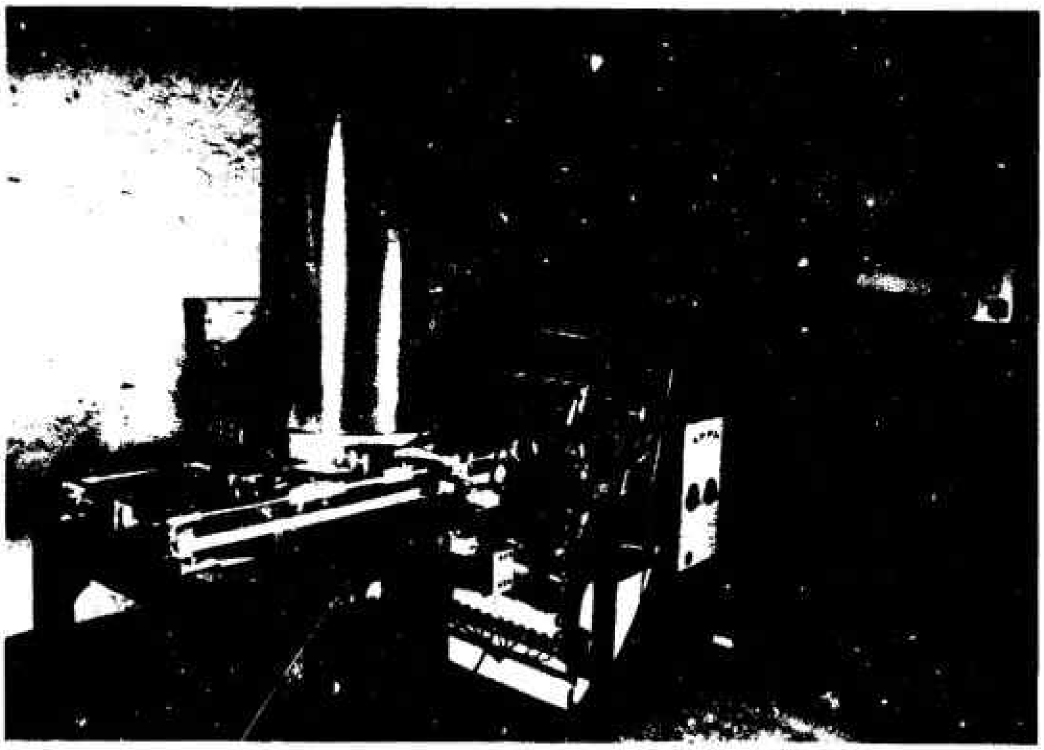

Fig. 25. Garraway Rapid Photographic Projection Printer.

specifications. At the same time, a 1:25,000 grid assembly was added. In May 1946, the Army Ground Forces requested the addition of a printing attachment that would handle roll film. This development was authorized in July 1946.

Only limited procurement of the Garraway printer occurred, because, in February 1944, the Army Ground Forces decided that the standard photographic section of the Army Battalion's mobile train, with its A-14 contact printers and Edward enlarger, should be issued to the Corps Company instead of the Garraway printer.

(8) Miscellaneous Investigations. In addition to the above outlined major accomplishments of this period, a number of other investigations are significant in terms of the overall problem and development of map reproduction equipment and techniques. Some of the most important of these developments will be noted in the following paragraphs.

(a) Bloom Process. In the period 1934 to 1936, Master Sergeant Fred H. Bloom, who had been assigned to the Engineer Board to work on map reproduction problems, developed a method of making fulltone lithographic plates direct from

continuous-tone photographic negatives without the use of a copy camera or halftone screen. The Engineer Board issued a pamphlet—Full Tone Reproduction—on the Bloom process around 1936, and a patent was granted in 1938.

This development was particularly significant at the time since the quantity reproduction of continuous tone imagery without loss of detail was a major problem and halftone techniques had not proved entirely satisfactory.

The Bloom process was used experimentally for a few years but was never adopted primarily because it was not consistently satisfactory in the field. In addition, the development of the halftone process became more profitable with the introduction of a 300-line contact screen.

(b) **Halftone Screens.** In 1939, the Engineer Reproduction Plant and the Eastman Kodak Company, Rochester, New York, began joint investigations with an acetate-film contact screen. This led to the successful development of 300-line and 150-line magenta contact screens by the end of 1942—a significant advance in the field of lithography. This development overcame to some extent the widespread prejudice against lithographed maps.

(c) **Map Paper.** In February 1940, the Chief of Engineers assigned project SP 309B jointly to the Engineer Board and the Engineer Reproduction Plant to conduct investigations to improve the 50 percent rag stock map paper which had been used up to that time. The assistance and advice of the Government Printing Office and the National Bureau of Standards were obtained, and working closely with leading paper mills, by mid-1943 a 48-pound paper that was highly resistant to water and oil and was considerably stronger than either sulphite or rag stocks was developed. This paper, called high wet strength paper, had remarkable characteristics well suited to military applications.

(d) **Microfilming.** The possibility of microfilming maps and photomaps on 35-mm film transparencies with sufficient quality that such miniatures could subsequently be used to make lithographic press plates or maps by enlargement was investigated in 1941 and 1942. The work was done primarily by the Engineer Reproduction Plant using the Huebner vertical camera as a test vehicle. It was concluded that it was impossible to achieve the necessary resolution in either black and white or color film and the project was abandoned.

(e) **Printing Plates.** Early in 1943, the Army Map Service tested a number of Plastolith (paper base) lithographic print plates produced by the Plastolith Company, Boston, Massachusetts. The tests showed that these plates had a number of advantages over the zinc plate then in use: They required no graining and thus eliminated

the need for a plate grainer; they could be coated manually, which made it possible to dispense with the plate whirler; they conserved critical zinc; their use resulted in lower costs; and their weight was only one-eighth that of zinc plates.

Further tests by the Engineer Board and the 654th Engineer Topographic Battalion in May and June 1943 confirmed the findings of the Army Map Service, and procurement of large numbers began in September 1943. Unfortunately, many of the plates procured proved defective due to poor packaging which permitted fungus to attack the plates. This was discovered about the time that the Engineer Board and the Army Map Service were testing two types of paper plates, the Lithomat and the Photomat, manufactured by the Lithomat Corporation, Cambridge, Massachusetts. Further, it was found that these plates were incapable of producing either halftone or line subjects to any degree of satisfaction, therefore, by March 1945, it was recommended that authorization for use of paper plates by topographic units be rescinded.

d. **Surveying Accomplishments Through World War II.**

(1) **General.** Before World War II, there was little or no research and development activity within the Army in the general field of surveying. Since surveying is an ancient art and the major surveying instruments had existed for many years, they were adopted and issued to the Army long before World War II.

In September 1939, the official report on the Military Mapping Service Test held in Southern California complained that the standard field surveying instruments were antiquated and unduly heavy and recommended that they be replaced by modern, lightweight, and more finely graduated instruments that would permit field work to be accomplished more rapidly. The research and development efforts through World War II were directed toward this end.

(2) **The 1-Second Direction Theodolite.** To establish a domestic source of supply and at the same time provide a superior theodolite for military troop use, the Engineer Board on 6 October 1939 recommended that a 1-second reading direction theodolite be developed. The Chief of Engineers, after surveying the possibility of development with several domestic surveying instrument companies, approved and assigned Project SP321, Military Theodolites, on 25 July 1940.

This project was beset with difficulties and exasperating delays from the outset. A development contract for two experimental models was awarded to W. & L.E. Gurley in September 1940, but the first experimental model was not shipped until November 1941. This instrument was unsatisfactory in both its optical reading and viewing systems and was returned to the manufacturer. The second experimental model, equipped with steel circles in lieu of the aluminum ones on the first model, was

inspected in June 1942 and was found still defective. It too was returned to the manufacturer and was remodeled and resubmitted in September 1942.

In the meantime the Bureau of Standards began work in December 1941 to devise methods of constructing glass circles like those used in European Theodolites. It reported some success in the project in mid-1942. In addition, the National Defense Research Committee was working on a new short telescope design for the theodolite. Therefore, in September 1942, the Engineer Board recommended[24] that, pending the incorporation of glass circles and an improved telescope, the Gurley theodolite be classified as substitute standard and procured only to meet urgent requirements. Also, in September 1942, a second development contract was awarded to the Keuffel and Esser Company to obtain an additional source.

A limited quantity procurement order (25 instruments) was placed with the W. & L. E. Gurley Company in October 1942, but production was delayed pending fabrication of an improved experimental model. An acceptable model was not completed until March 1944. It incorporated the newly designed telescope but still had steel rather than glass circles (Fig. 26). Nevertheless, the manufacturer was instructed to proceed with production.

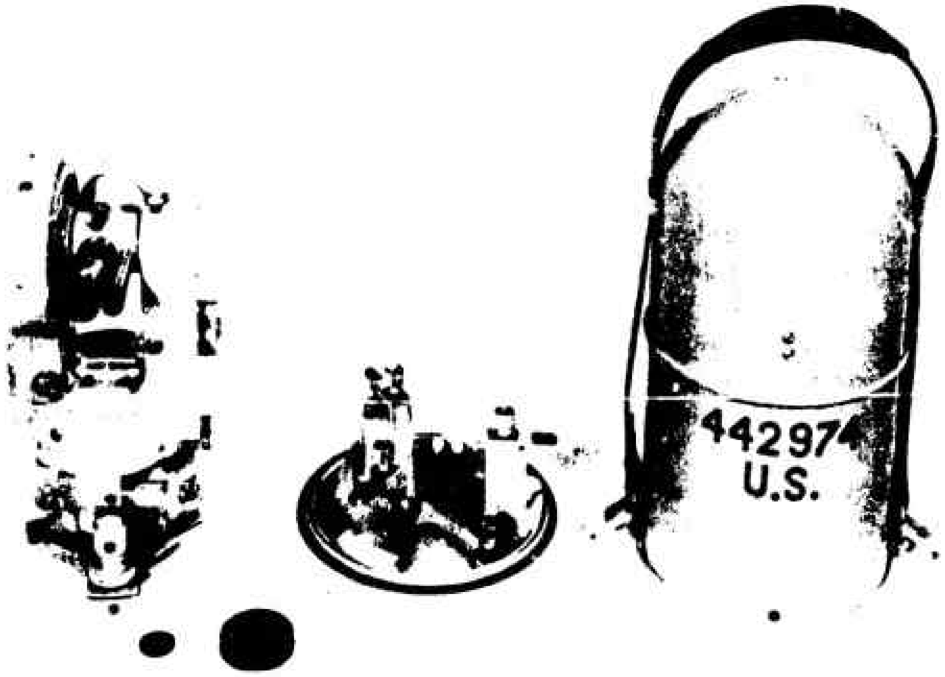

Fig. 26. Gurley 1-second Direction Theodolite, 1944.

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[24] "One Second Theodolite," Engineer Board Report 722, 19 September 1942.

By the end of the war, only 15 units had been delivered on the W. & L.E. Gurley production order, and the Keuffel and Esser Company had not yet delivered experimental models under its development contract.

(3) **Military Level.** The development of a new military level was authorized in March 1941 to provide an instrument more efficient than the standard issue dumpy level and lighter in weight than the precision level. On 30 April 1941, the Engineer Board awarded a development contract to C. L. Berger and Sons, Inc., Boston, Massachusetts, for a new military level which was to be a modification of their tilting level. The experimental model was tested in December 1941, and a second improved model was ordered. This improved model was tested in the summer of 1942, was found satisfactory, and was subsequently adopted to supersede the precision level entirely and the dumpy level for issue to mapping units.

(4) **Surveying Altimeters.** The wartime role of the Engineer Board on surveying altimeters was principally one of testing surveying altimeters marketed by Wallace & Tiernan Products, Inc., Belleville, New Jersey, working with the manufacturer to improve the design for military application, and preparing procurement specifications. This work began in March 1942,[25] and both the 6000-foot and the 15,000-foot altimeters were standardized on 31 March 1943 (Figs. 27 and 28).

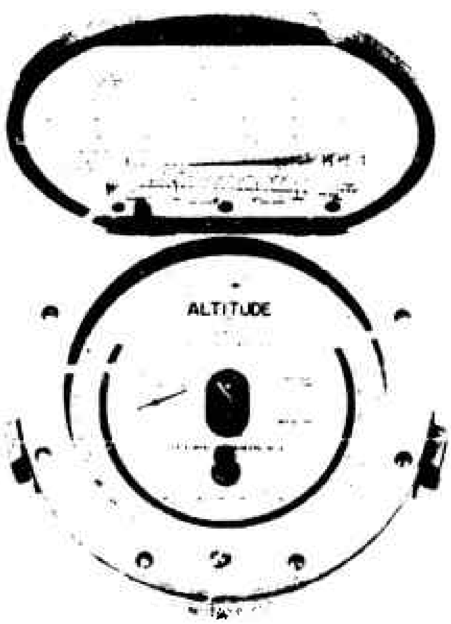

Fig. 27. Surveying Altimeter 6000 feet.

[25] "Surveying Altimeters," Engineer Board Report 723, 4 December 1942.

Fig. 28. Surveying Altimeter – 15,000 feet.

(5) **Survey Computer.** The first attempt to develop a computer for surveying application began in 1940 when Captain Louis J. Rumaggi, then Commanding Officer of the 30th Engineers, proposed that a computer be developed to speed the reduction of survey data to provide control for photogrammetric mapping. A machine that would calculate latitudes and departures to an accuracy of 1 part in 30,000, given range and azimuth survey data, was required.

In September 1940, a development contract for such a device was negotiated with the W. L. Maxon Corporation, New York City. It soon became evident that the contractor had undertaken more than he could accomplish, and it was not until April 1943 that the experimental model was ready for examination.

This device was a mechanical computer similar to those produced at that time with sine and cosine cams included for the solution of the survey problem. It was noisy, frequently jammed, and did not meet the accuracy required even when it operated smoothly. Since the item was unacceptable and could not be corrected, the contract was cancelled; and no further attempt to develop a survey computer was made until after the war.

(6) **Astronomical Position Finding Equipment.** On the eve of World War II, an urgent requirement developed for a more accurate and rapid method and equipment for astronomic position location than the Navigation Equipment Set No. 1 which was then available. (This set consisted of an octant and a navigation watch.) The astronomical position finding equipment was needed primarily to establish reliable position for basic map and chart control.

This requirement had been anticipated by the Engineer Board, and the development of a suitable astronomical position set had begun in December 1940.

The first approach to this problem was the development of an astrolabe, or equiangulator, an instrument for determining the position of the observer by observing the passage of stars across a circle of equal altitude. During the 1941 to 1943 period, the following types were procured for comparative testing (all were experimental models with the exception of the one manufactured in London):

(a) 45° pentagonal-prim astrolabe – Cooke, Troughton & Simms, Ltd., London (weight 11 pounds).

(b) Type A1 60° prismatic astrolabe – Eastman Kodak Company, Rochester, New York (weight 56 pounds).

(c) Type A1A, the A1 rebuilt by David Mann, Lincoln, Massachusetts (weight 83 pounds).

(d) United States Naval Observatory model – the A1 redesigned by the Naval Observatory (weight 101½ pounds).

(e) Gaertner Model – the A1 redesigned, in part, by Dr. I.C. Gardner, National Bureau of Standards, and built by the Gaertner Scientific Corporation, Chicago, Illinois (weight 84½ pounds).

(f) 60° split-telescope astrolabe, – designed by J. E. Willis, astronomer, U. S. Naval Observatory, and built by the Observatory (weight 75 pounds).

(g) First experimental model of the 60° pendulum astrolabe, a new type invented by J. E. Willis in 1942 to 1943 and built by the Naval Observatory (weight 74½ pounds).

(h) Second experimental model of the 60° pendulum astrolabe built by the David White Company, Milwaukee, Wisconsin (weight 34 pounds) (Fig. 29).

These investigations resulted ultimately in the selection of the pendulum astrolabe, and the Engineer Board recommended in February 1944[26] that the

[26] "Astrolabes (Equiangulators)," Engineer Board Report 791, 5 February 1944.

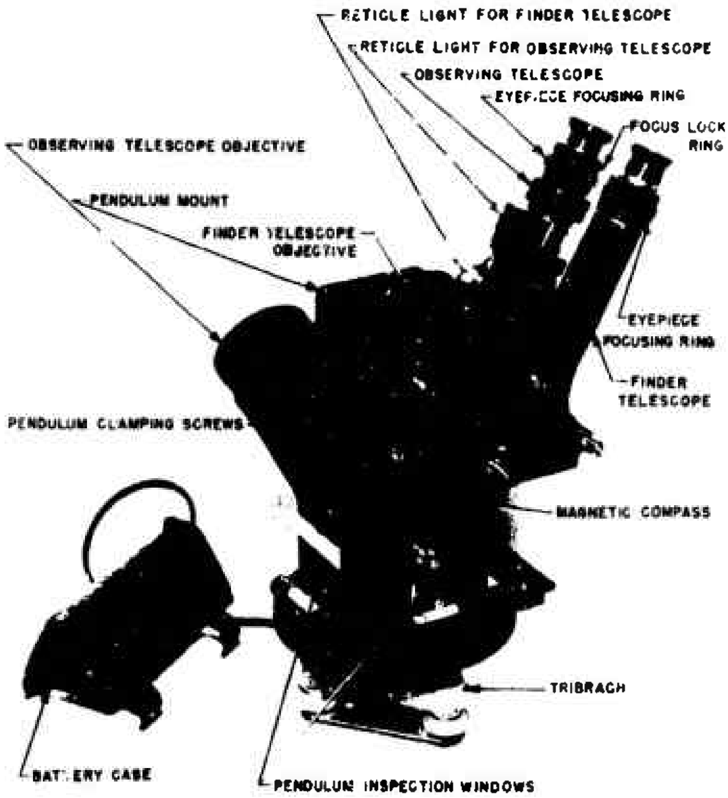

Fig. 29. 60° pendulum astrolabe manufactured by David White Company.

pendulum astrolabe be standardized and procured for issue in place of the 20-inch transit in the astronomical position set.

While the astrolabe was being developed, the Army Air Forces became interested in the Zenith camera approach to astronomic position location. The Army Air Forces, in conjunction with the Eastman Kodak Company, had designed a 24-inch focal length Zenith camera in 1941.

A pilot model of the Air Force-Eastman design, delivered on an Engineer Board contract in August 1943, was tested at the Naval Observatory and found quite accurate. However, it weighed about 180 pounds. Therefore, it was decided to develop a more compact and simplified camera with approximately 12-inch focal length.

Military characteristics for the simplified Zenith camera (Fig. 30) were prepared by the Air Force. In January and February 1944, the Engineer Board ordered experimental models from the Eastman Kodak Company and from David W. Mann. These models were delivered in August 1944 and were immediately tested by

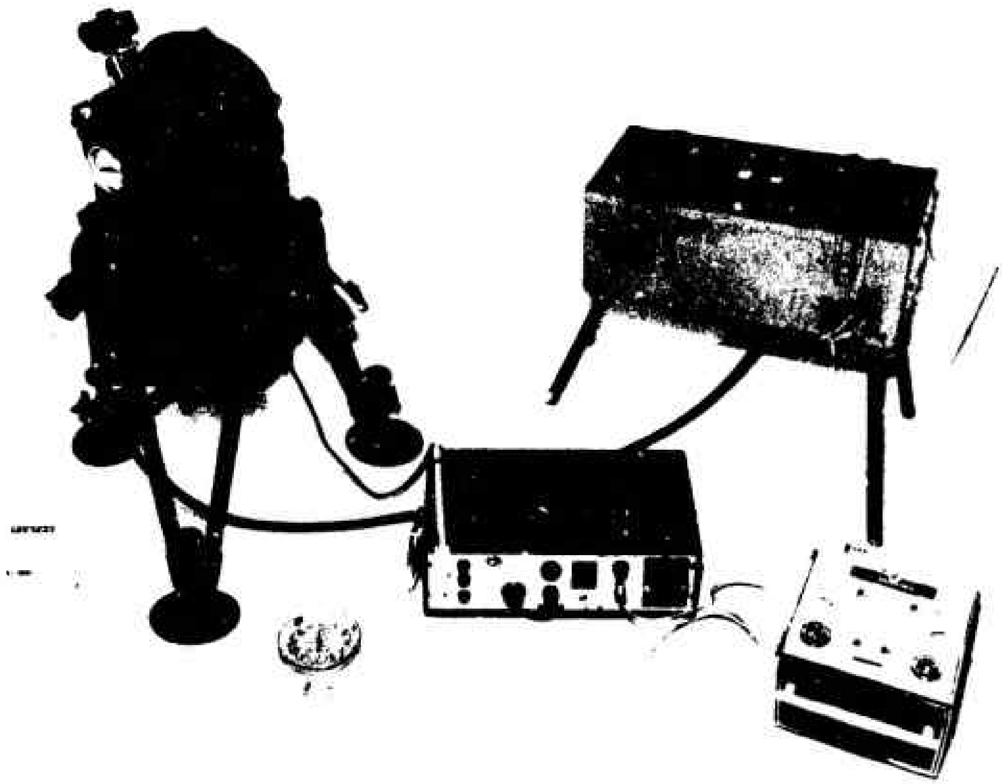

Fig. 30. Zenith camera equipment.

the Engineer Board, the Naval Observatory, and the 311th Photo Wing. Testing resulted in the decision to adopt the Mann camera. Although both cameras were sufficiently accurate, the Mann camera weighed less than 30 pounds and was considered more suitable for field use. A final report[27] on this development was submitted by the Engineer Board in May 1945 recommending that the project be closed.

Along with the Zenith camera development, the Engineer Board also developed a small comparator for measuring the star plates. Six of these comparators were ordered from the David W. Mann Company in June 1943. The first was examined by representatives of the Engineer Board in August 1943 and was later tested with favorable results by the National Bureau of Standards and the 311th Photo Wing. The project, MP 415, was closed in June 1945.

Also in the period 1943 to 1945, the Engineer Board spent considerable effort on the investigation of timepieces for use in astronomical position location

[27] "Investigation and Test of Zenith Cameras," Engineer Board Report 932 Final Report, 14 May 1945.

and radar receiving sets for calibration of the timepieces against time signals broadcast by the Naval Observatory. As a result of investigations, a break-circuit marine chronometer[28] was adopted and an Engineer Board Manual on timepieces was prepared.[29] The investigations of radio receivers resulted ultimately in the recommendation that the standard AN/PRR-1 be adopted.

(7) **Compasses.** Although the compass is not strictly a surveying instrument, considerable effort was expended by the Mapping Branch of the Engineer Board in the World War II period on the development of small compasses for Infantry and other arms.

The work started in 1938 when the Infantry requested that an inexpensive, commercial-type compass be found to replace the marching compass then issued because the marching compass was too large, elaborate, and costly. This investigation was assigned to the Engineer Board, and it was soon found that no suitable commercial compass was available. The W. & L.E. Gurley and the Taylor Instrument Companies, however, were willing to make a suitable compass based on a new design; and each company made six samples in 1939 as ordered from the Engineer Board.

After testing by both the Infantry and Cavalry and some modification by the manufacturers, in November 1940 the Engineer Board recommended procurement of the cheap lensatic compass from both manufacturers.

Since the mechanical dampening arrangement in all compasses available up to that time had not been entirely satisfactory, the Engineer Board started investigations of liquid dampening in December 1941. Compasses of both the lensatic and the wrist type with liquid dampening were developed, tested, and adopted in the 1942 to 1944 period; and it was thought for a time that the compass problem had been solved. However, it was discovered that, with temperature changes, an air bubble often developed in the compass capsule which impeded the free movement of the compass needle and affected the accuracy.

In July 1944, the Superior Magnetic Corporation, one of the liquid-filled-compass suppliers, solved the liquid dampening problem by applying the induction dampening principle. The compass body was made of copper which set up an eddy current and magnetic field as the compass needle rotated, thus acting as a drag to dampen the needle oscillation. Samples were immediately procured and tested. As a result, the induction dampened wrist compass was standardized in April 1945, and the induction dampened lensatic compass was standardized in May 1945.

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[28] "Investigation of Timepieces for Astro Fixes," Engineer Board Report 920, Final Report, 24 March 1945.

[29] "Technical Instructions on Care and Use of Timepieces," Engineer Board Manual, May 1945.

(8) **Miscellaneous Investigations.** In addition to the above major programs, there were a number of other investigations, the more significant of which are noted in the following paragraphs.

(a) **Military Slide Rule.** In June 1942, the Field Artillery Board requested that a slide rule be developed to solve base triangle problems, and this development was assigned to the Engineer Board. Working closely with the Field Artillery, the Engineer Board developed and recommended for adoption in October 1942 a 20-inch slide rule graduated in mils. Later, in 1944, this design was replaced by a 10-inch engine-divided rule manufactured by the Keuffel and Esser Company for the Field Artillery School.

(b) **Special Navigation Equipment.** In February 1942, the Chief of Engineers approved a program for providing navigation aids for desert fighting which had been proposed by the Engineer Board. Under this program, the Engineer Board recommended two navigation sets (Set No. 1, Celestial, and Set No. 2, Dead Reckoning) in May 1942. These were standardized in September 1942, and tentative field manuals to accompany the sets were prepared by the Engineer Board.[30]

An interesting part of this investigation was the development of the land sextant, invented by Captain William S. Little of the Mapping Branch, Engineer Board. Essentially a clinometer that had a low-power telescope with cross hairs and illumination for night operations, it was designed for making rough astro-fixes. It was developed because of the fear that bubble octants would not be available in sufficient quantities. The land sextant weighed only 5 pounds. Models of the land sextant were built by the Engineer Depot, Columbus, Ohio, in September 1942 and by the Naval Observatory in December 1942. The project was dropped in 1943 since the shortage of bubble octants did not develop as anticipated.

(c) **Subtense Method.** In the subtense method of distance measurement, the distance is calculated from the horizontal angle subtended at the surveying instrument by a horizontal bar of fixed length at the distant point. This method was investigated in 1940 by both the 29th and the 30th Engineers. Although satisfactory results were obtained using a Wild T2 theodolite, no further action was taken until December 1943 when the matter was reopened by the Chief of Engineers. Comparative tests were then conducted of the subtense method and a short-base triangulation method by the 651st Engineer Topographic Battalion. These tests showed the subtense method the more suitable, and as a result the Engineer Board recommended that

[30]"Navigation for Ground Forces: Part I, Celestial Navigation; Part II, Dead Reckoning," EB Tentative FM, 11 March 1943.

a subtense bar be developed for units equipped with the 1-second theodolite.[31] No further action was taken on this recommendation through World War II.

(d) **Plotting Boards.** In June 1944, the North African Theater Headquarters suggested the development of a night-illuminated plastic grid table to provide a more suitable means for plotting survey data for artillery fire control. At that time, paper firing charts thumb-tacked to wooden plotting boards were being used. The problem was assigned to the Engineer Board, and experimental models in the two sizes requested, 28 inches by 28 inches and 38 inches by 38 inches, were built in the Engineer Board Shops. These were approved by representatives of the Army Ground Forces and were standardized in February 1945 less than 8 months after the suggestion was made by the North African Theater.

19. Research and Development Programs, World War II to 1960.

a. **Introduction.** By the close of World War II, there were only 15 active research and development projects in the topographic engineering field with an annual expenditure of approximately $150,000. The active projects at VJ day were:

		Closed
MP 321	Military Theodolite	
MP 321A	Military Theodolite	Sep 46
MP 488	Rectifying Camera	
MP 580	Airborne Camera and Photo Process Equipment	
MP 581	Airborne Press, Lithographic Offset	
MP 593	High Oblique Multiplex Projector	
MPS 205C	Improvements in Map Technique	24 Jul 46
MPS 205C (2)	Inspection of Multiplex Equipment	24 Jul 46
MPS 205C (3)	Vertical Control for Aeronautical Charting	24 Jul 46
MPS 205E	Wide Angle Mapping Equipment	12 Sep 47
MPS 205E (1)	Camera Calibrations	12 Sep 47
MPS 408	Investigation and Modification of Photomapping Equipment and Technique	12 Dec 47
MPS 409	Investigation and Modification of Map Reproduction Equipment and Techniques	12 Dec 47
MPS 410	Investigation and Modification of Surveying Equipment	12 Dec 47
MPS 453	Relief Maps	12 Dec 48

[31] "Field Tests of Short-Base Triangulation and Subtense Bars," Engineer Board Report 870, 22 September 1944

After VJ day, the funding level for topographic research and development was greatly increased, with a concurrent increase in personnel strength in the Topographic Engineering Department. Programs were implemented to re-equip topographic troop units with items properly designed for field application to replace items adopted in haste during World War II. Most of the research and development projects active at VJ day were either closed or superseded by new projects in the 1946 to 1947 period because new military characteristics were developed based on wartime experience and advances in materials and methods.

In September 1947 the system for numbering projects was changed. In the period from 15 August 1945 to 30 June 1950, the projects approved and worked on were:

8-34-05-003	Compass, Lensatic
8-34-05-004	Compass, Sun, Universal
8-34-05-005	Azimuth Determination Methods
8-34-05-006	Compass, Wrist
8-35-01-001	Authorized Investigations, Mapping, Charting and Geodesy
8-35-01-002	Authorized Investigations, Aerial Photographic Equipment for Mapping
8-35-02-001 (Old MP 745)	Field Artillery Plotting Equipment*
8-35-02-002	Cartographic Bases, Stable*
8-35-02-003	Range Deflection Instruments and Accessories*
8-35-03-001	Rectifying Camera*
8-35-03-002	High Oblique Multiplex Projector*
8-35-03-003 (Old MP 742)	Projector, Reflecting, Portable*
8-35-03-004 (Old MP 747)	Camera, Rectifying, Tilts to 20 degrees, Autofocus, 9 by 9 inch*
8-35-03-005 (Old MP 751)	Photomapping Equipment Motorized*
8-35-03-006 (Old MP 802)	Stereoscope, Magnifying, Mirror, Folding w/Detachable Binoculars and Case*
8-35-03-007	Instruments, Plotting, Stereoscopic, Multiplex, Set No. 7 Short Frame*
8-35-03-008	Stereoplotter, Topographic, Portable*
8-35-03-009	Templet, Slotted, Mechanical, Set*
8-35-03-010	Height Finder, Oblique, Topographic*
8-35-03-011	Sketchmaster, Oblique*

*Projects active as of 30 June 1950.

8-35-03-012	Photoangulator, Topographic*
8-35-03-013	Multiplex Equipment Motorized*
8-35-03-014	Mapping with Minimum Ground Control*
8-35-04-001 (MP 799)	Computer Survey Electronic*
8-35-04-002 (MP 831)	Geodesy for Navigation of Long Range Guided Missiles*
8-35-05-001 (MP 828)	Utilization of SHORAN for Mapping*
8-35-05-002 (MP 868)	Utilization of Ground Survey Electronic Equipment for Mapping*
8-35-05-003	Utilization of Radar Presentations for Topographic Mapping*
8-35-07-001	Terrain Model Production Methods*
8-35-07-002	Terrain Model Making Equipment, Mobile
8-35-08-001 (MP 800)	Application and Utilization of Very High Altitude Aerial Photography for Mapping*
8-35-08-002 (MP 804)	Color Photography Applied to Mapping*
8-35-09-001	Camera, Copying, Mobile, Process, 24 by 30 Inch*
8-35-09-002	Press, Lithographic, Offset, 22.5 by 29 Inch*
8-35-09-003	22- by 29-Inch Spirit Duplicator*
8-35-09-004 (MP 735)	Cutter, Paper, Hand and Power Operated, Lightweight, 30.5 Inch*
8-35-09-005 (MP 739)	Reproduction Equipment, Ammonia Process*
8-35-09-006 (MP 760)	Infrared Light Sources for Lithographic Process*
8-35-09-007 (MP 790)	Reproduction Equipment, Topographic, Motorized Map Layout Section, Set No. 2*
8-35-09-008 (MP 791)	Photo Lettering Machine*
8-35-09-009	Rapid Production of Photographic Prints for Ground Force Use*
8-35-09-010	Lithographic Research Applied to Map Reproduction in the Field*
8-35-10-001	Theodolite, 1 Second*
8-35-10-002 (MP 577)	Theodolite, 10 Second*
8-35-10-003 (MP 798)	Tower, Triangulation, Lightweight*
8-35-10-004	Altimeter, Surveying*
8-35-10-005	Helicopter Survey Method for Mapping*
8-35-10-006	Tribrach, Universal*
8-35-10-007	Tripod Universal*
8-35-10-008 (MP 867)	Surveying Equipment, Mobile Control Section*
8-35-10-009	Theodolite, 1 Minute
8-35-10-012	Comparator, Radio Time*
8-35-10-013	Astronomic Orientation Attachment*
8-35-10-014	Pedometer, Stride Registering*

*Projects active as of 30 June 1950.

In the period from 1950 to 1960, many of these projects were successfully completed, resulting in either standardization of an item of equipment, substitution or addition of the item to appropriate sets of equipment, or the publication of a formal report.

Again, around 1950, the annual funding level almost tripled to approximately a nine-fold increase over the last year of World War II. The program continued to concentrate on solving problems of field topographic troop units, although a number of exploratory programs were conducted. These formed a solid foundation on which to build the research and development program of the 1960's. There was also greater emphasis given to basic and applied research, particularly in the late 1950's, in various scientific disciplines for new principles and techniques pertinent to surveying, geodesy, mapping, position determination, targeting, cartographic drafting, information display and dissimination, and map reproduction for application to meeting both tactical and strategic requirements for geodetic and mapping data.

New projects initiated during the 1950's were:

8-35-02-104	Cartographic Drafting Methods and Equipment – Approved 7 Sep 1951
8-35-03-122	Precision Globes and Spherical Map Sections – Approved 7 Nov 1952
8-35-03-215	Stereoplotter, Topographic, Projection Type, High Precision – Approved 12 Jan 1951
8-35-03-216	Rectifier, Photogrammetric, for 9-Inch by 18-Inch Photography, 12- and 24-Inch Focal Lengths, Autofocusing – Approved 3 Aug 1951
8-35-03-217	Printer, Photographic Reduction, Multiplex, Variable Ratio, for 6-Inch Photography With Planigon or Metrogon Lens – Approved 4 Jan 1952
8-35-03-218	Photodelineator, Oblique – Approved 7 Nov 1952
8-35-03-220	Convergent Photography in Mapping, Equipment and Techniques for Utilization of
8-35-03-221	Processing Equipment Diapositive for Stereophotogrammetric Mapping Requirements – Approved 5 Dec 1952
8-35-03-222	Map Revision Techniques and Equipment – Approved 3 Aug 1956
8-35-03-520	Orthographic, Photogrammetric Printer – Approved 6 Sep 1957
8-35-03-100	Fundamental Factors for Map Compilation and Control
8-35-03-118	Basic Error Factors in Stereophotogrammetry – Approved 7 Mar 1952
8-35-03-121A	Basic Research for Topographic Mapping
8-35-03-460	Convergent Photography in Mapping, Equipment and Techniques for – Approved 2 Apr 1954
8-35-03-540	Army Photo Imagery Interpreters Kit – Approved 2 Dec 1959

8-35-09-111	Modification of Motorized Map Reproduction Sections – Approved 6 Oct 1950
8-35-09-112	Xerography, Application to Map Reproduction – Approved 4 Jan 1952
8-35-09-113	Press, Lithographic Offset, Web-Fed, for Map Reproduction – Approved 7 Mar 1952
8-35-09-114	Aerial Photo Reproduction Equipment Motorized – Approved 12 Sep 1952
8-35-09-115	Separator, Color Scanning Topographic Map – Approved 1 Jul 1955
8-35-09-116	Press, Offset, Lithographic, Two Color 22½- by 30-Inch – Approved 1 Feb 1957
8-35-09-117	Target Map Coordinate Locator Equipment – Approved 28 Mar 1958
8-35-10-115	Tripod, Ranging Pole – Approved 4 Aug 1950
8-35-10-116	Geodimeter for Measuring Distances by Lightwaves – Approved 2 Feb 1951
8-35-10-117	Target, Light, Pole, Ranging – Approved 5 Oct 1951
8-35-10-118	Triangulation Traverse Equipment – Approved 1 Feb 1952
8-35-10-119	Indirect Distance Measurement – Approved 5 Dec 1952
8-35-10-120	Use of Army Aircraft in Survey Operations – Approved 5 Dec 1952
8-35-10-121	Computer, Survey, Electric – Approved 7 Aug 1953
8-35-10-122	Computer, Traverse, Portable – Approved 2 Feb 1951
8-35-10-123	Utilization of Ground Survey Electronic Equipment for Mapping – Approved 5 Sep 1947
8-35-10-124	Automatic Position Survey Equipment – Approved 7 Dec 1956
8-35-10-125	Geodimeter, 3-Kilometer Range – Approved 2 Aug 1957
8-35-10-126	Geodimeter, 30-Kilometer Range
8-35-10-580	Theodolite Automatic Tracking – Approved 5 Sep 1958
8-35-10-600	Artillery Survey System – Approved 5 Sep 1958
8-35-10-620	Inertial Survey Equipment – Approved 3 Oct 1958
8-35-11-105	Target Location for Army Surface-to-Surface Missile
8-35-11-106	Analytical Photogrammetry – Approved 5 Oct 1956
8-35-11-540	Automatic Map Compilation Techniques and Equipment – Approve 6 Sep 1957
8-35-11-580	Ultra Wide Angle Photography in Mapping, Equipment and Techniques for the Utilization of – Approved 6 Nov 1959
8-35-12-400	Research for Surveying and Geodesy
8-35-12-400	Research for Map Compilation
8-35-12-440	Research for Map Reproduction

b. **Photomapping Accomplishments, World War II to 1960.**

(1) **Tri-metrogon Equipment.** At the close of World War II, work was in progress to improve means for exploiting the tri-metrogon photography, particularly

for contouring. Two approaches were being pursued by the Engineer Board. One of these was to rectify the oblique photographs as a step in map compilation. Experimental model rectifiers were ordered – one from the Aero Service Corporation, Philadelphia, Pennsylvania, and the other from the Bausch and Lomb Optical Company. The other approach was using specially designed high oblique multiplex projectors. Eighteen of these projectors were procured from the Bausch and Lomb Optical Company for test purposes.

Neither of the experimental model rectifiers was satisfactory, so a contract was awarded to Fred P. Wilcox, Bethesda, Maryland, to modify the Bausch and Lomb model to provide an improved light source, increased rigidity for van mounting, and a more satisfactory method for setting and locking the motions (Fig. 31). This was completed in 1948 and engineering tests were made in 1948 and 1949.[32] This instrument was a horizontal projecting type, with circles and scales for mechanically setting computed angles as well as negative to lens and lens to easel distances. It was designed to rectify 6-inch focal length photography with tilts up to 70° and 12-inch focal length photography with tilts up to 30°. Service test of this item was waived by the Army Field Forces, and it was classified standard in April 1951.

Fig. 31. High Oblique Rectifier – Bausch and Lomb model modified and rebuilt by Fred P. Wilcox.

[32]"Printer, Photographic, Horizontal Projection, Rectifying, Tilts Under 70° for 9½-Inch Aerial Roll Film," ERDL Report No. 1161, 13 March 1950.

The oblique multiplex projectors were tested by the Engineer Board and also by the Army Map Service in 1950. It was found that although the oblique multiplex projectors met all requirements of the adopted military characteristics, they were not sufficiently superior to the converted vertical projector developed during the War to warrant classification as a standard item.[33]

Other items of tri-metrogon equipment were worked on in the post-World War II period under projects designed to provide items acceptable for common use by the Air Force, Corps of Engineers, and the Army Ground Forces. These were a photoangulator (Fig. 32), a mechanical slotted templet set (Fig. 33), an oblique sketchmaster, and an oblique height finder for measuring elevations on contact prints of tri-metrogon aerial photography (Fig. 34). The photoangulator was completed in 1950,[34] and the item was classified standard in April 1951. The development of the

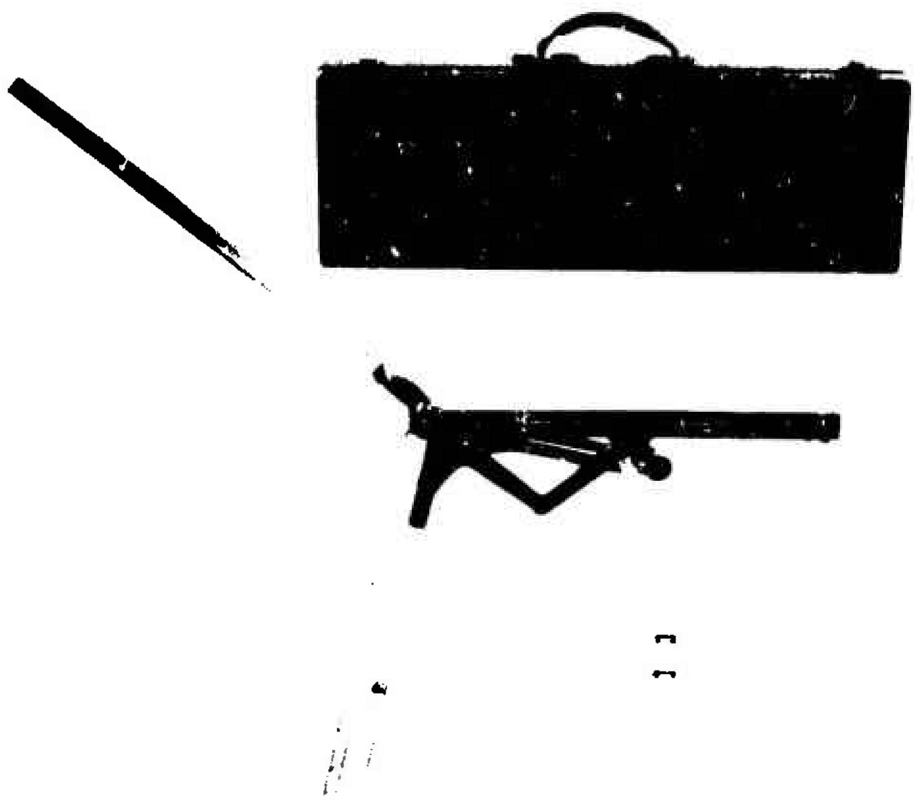

Fig. 32. Photoangulator for use with tri-metrogon oblique photography

[33] "Development of Projector, Multiplex Oblique, Wide Angle," ERDL Report 1204-L, Final Report, 31 May 1951.

[34] "Photoangulator," ERDL Report 1185, 18 October 1950.

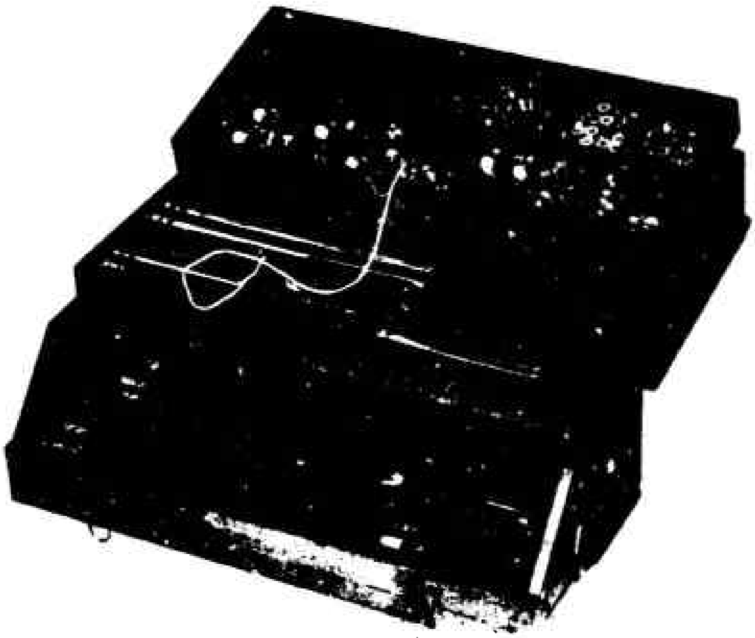

Fig. 33. Mechanical Slotted Templet Set.

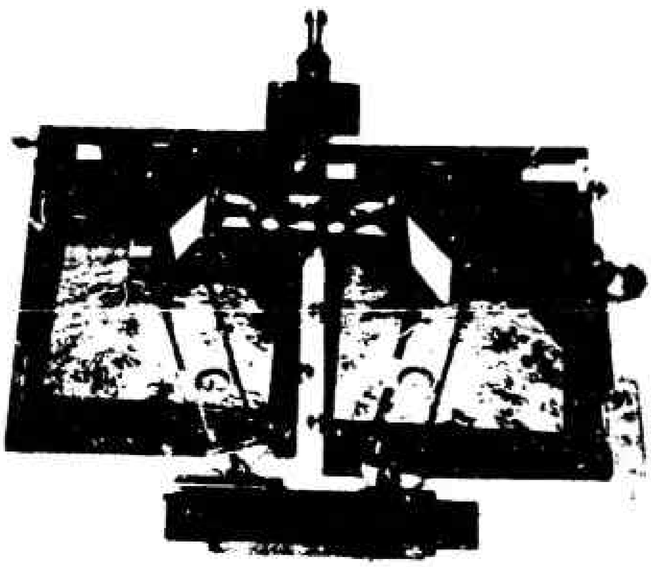

Fig. 34. Experimental Oblique Height Finder.

mechanical slotted templet set was completed in 1951,[35] and the item was classified standard in September 1952. The Oblique Sketchmaster development was completed in 1952.[36] The development of the Oblique Height Finder was not completed until 1955[37] when the item was classified standard.

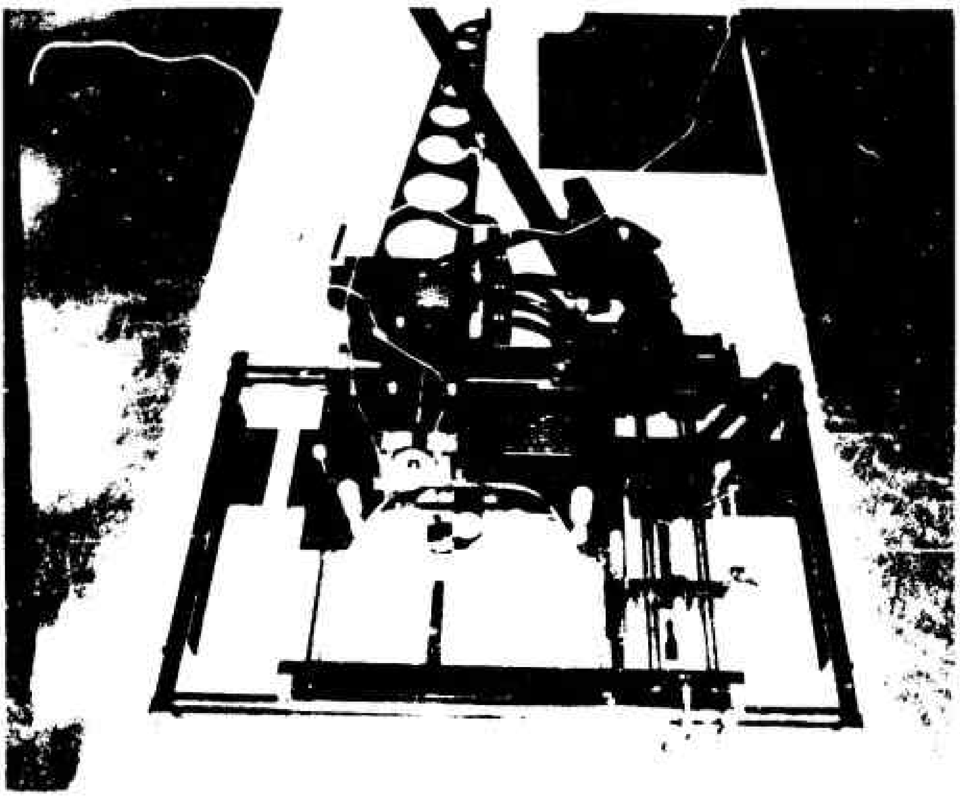

Fig. 35. Oblique Photodelineator.

The Oblique Photodelineator was another item of tri-metrogon equipment worked on in the mid 1950's (Fig. 35). This item, approved 7 November 1952, was intended to provide a simple sketching instrument to facilitate compiling maps from oblique tri-metrogon aerial photography and to overcome operational deficiencies of the Oblique Sketchmaster. An engineering test model was developed under contract by the Scientific Engineering Company. As a result of engineering tests of this model, it was concluded that, although the design principles were theoretically sound, the aims of the project could not be achieved with a simple mechanical device

[35]"Slotted Templet Set With Radial Stainless Steel Arms and Plywood Chest," ERDL Report 1208, 25 July 1951.

[36]"Oblique Sketchmaster," ERDL Report 1274, 14 December 1952.

[37]"Development of Height Finder, Oblique, Topographic," ERDL Report 1383, 8 November 1954

and that further development of the instrument would result in a large precision instrument both difficult and expensive to produce. It was further concluded that development of sketching equipment of this type would offer only marginal improvement over present equipment. This project was cancelled in October 1957.

(2) Photogrammetric Rectifier. While a horizontal projecting rectifier was under development in the late 1940's, primarily for the rectification of the oblique tri-metrogon photographs as noted previously, another rectifier development was initiated in November 1946 to provide an automatic focusing, vertical projecting rectifier suitable for installation in a mobile mapping van and capable of rectifying 9-inch by 9-inch photography of either 6-inch or 12-inch focal length with tilts up to 20° (Fig. 36). This device was to be applied primarily to the production of controlled mosaics as a topographic map substitute. Up to this time, only European manufacturers produced equipment of this type, and it was not designed for installation in mobile mapping vans.

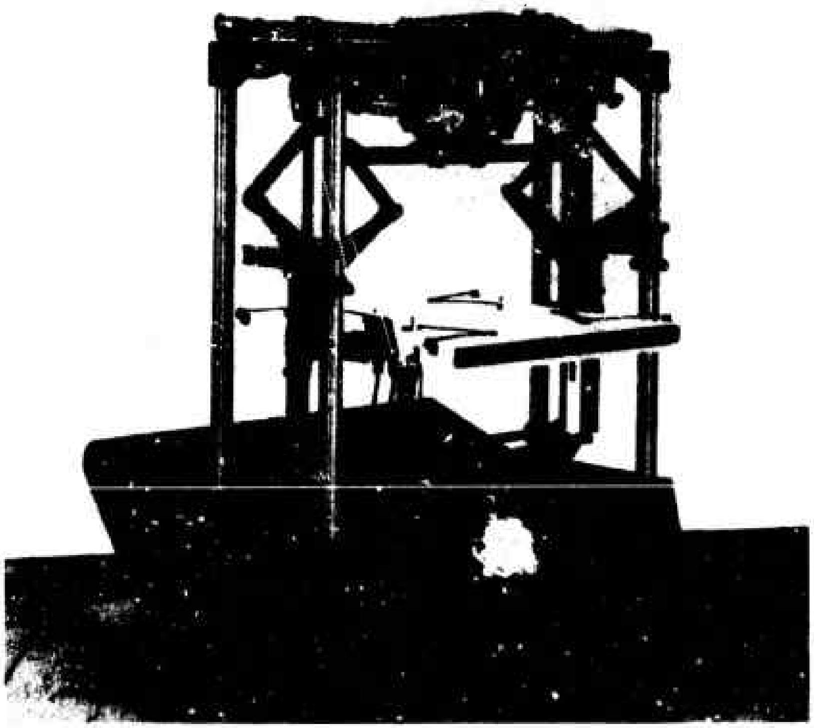

Fig. 36. Automatic Focusing Vertical Projecting Rectifier.

This development proceeded smoothly without any unusual complications or delays. A development contract was negotiated with the Bausch and Lomb Optical Company, Rochester, New York, and an experimental model was delivered to ERDL in January 1948. Two service test models were ordered in June 1949, and the

contract was modified shortly thereafter for three additional instruments for the Aeronautical Chart Service, the Corps of Engineers, and the Navy. Before delivery of these instruments began, another contract was awarded for seven additional instruments in May 1950. By 1952, service tests by the Air Force and the 656th Engineer Topographic Battalion were completed,[38] the item was classified standard, and the project was closed in September of that year.

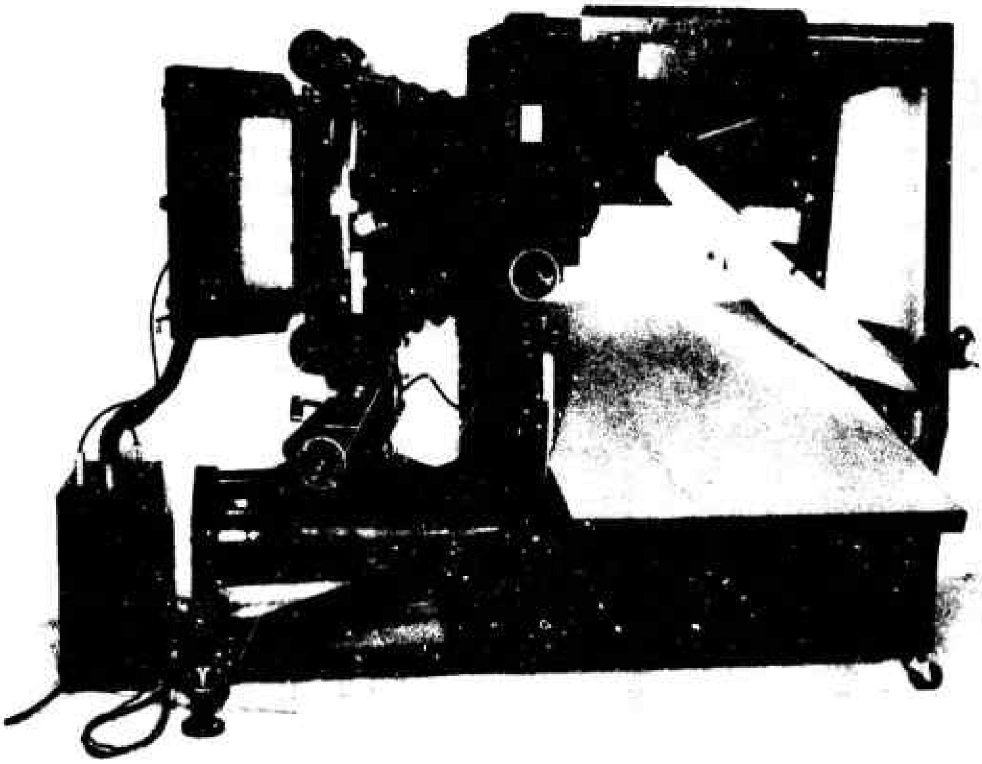

Fig. 37. Autofocusing Rectifier, 9 by 18 inch.

In the meantime, interest had developed in the use of long focal length photography with 9-inch by 18-inch format in multiple camera installations to supplement basic mapping coverage and to provide sufficient scale and image quality to identify topographic map detail. Consequently, in August 1951, a project was initiated to develop an autofocusing rectifier (Fig. 37) for this photography so that it could be used for mosaic construction. The military characteristics called for the rectification of 6-inch focal length photography with tilts to 10°, 12-inch focal length photography with tilts to 20°, and 24-inch focal length photography with tilts to 30°. It was also to be suitable for mobile van installation.

[38] "Development Service Tests, and Production Model Tests and Autofocusing Rectifier," ERDL Report 1307, 7 July 1953.

The Kargyl Company, San Antonio, Texas, was contracted for an experimental model, and the Bausch and Lomb Optical Company was contracted to develop a special 14-inch focal length, wide-angle projection lens for the rectifier.

Engineering tests of the experimental model were completed in 1956,[39] and the experimental item was modified by Reed Research Inc., Washington, D.C., to provide a model for service test by the 66th Engineer Topographic Company. By 1959, all development and test work on this item had been completed.

The design of this rectifier was unique; the optical path was bent through 90° so that the negative plane was nominally vertical and the easel was nominally horizontal. This design provided an instrument sufficiently compact for van mounting and, with the nominally horizontal easel, trial and error rectification to control was conveniently accomplished.

(3) **Motorized Photomapping Equipment.** During World War II, photomapping facilities were not mounted in trucks as were the map reproduction facilities, so a development program to correct this deficiency and consequently to increase the operational efficiency of the topographic service available to the Field Army was initiated in January 1947. This development was destined to pursue a long course, and it was not completed until 1958.

Initial studies indicated the need for 12 or 13 van-type trucks for the Photomapping Company of the Army Topographic Battalion and 3 or 4 vans for the Photomapping Platoon of the Corps Topographic Company. It was intended that the experimental ordnance T-1 van[40] with expansible sides be used. However, engineering tests concluded that the van was not suitable, primarily because of the impracticability of expansion and retraction, the lack of structural rigidity, and inadequate weatherproofing.

In the meantime, an investigation was made of the practicability of using multiplex equipment mounted in a van-type truck in Army Topographic Battalions. These investigations included service testing by the 62nd Engineering Topographic Company[41] of a standard frame and table with nine wide-angle multiplex projectors, a standard reduction printer, and a darkroom facility mounted in a reproduction-type van. As

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39. "Test and Evaluation of 9 by 18 Rectifier for 12- and 24-Inch Focal Length Photography," ERDL Report 1460-TR, 7 September 1956.

40. "Body Expansible, T-1," ERDL Report 1187, 24 October 1950.

41. "Test of Motorized Multiplex Equipment," Army Field Forces Board No. 2, Project No. P-117?, 14 December 1950.

a result of these tests, it was concluded that motorized multiplex equipment was suitable for use by Field Army Topographic Units.[42]

Because of the urgent need for a suitable expansible-type van, the Corps of Engineers was authorized in May 1951 to develop an expansible van body along a different approach.[43] [44] In the interim, because of the uncertain world situation in 1951, plans were developed for an interim system based on placing heavy technical equipment in two 17-foot solid wall map-reproduction-type vans and using prefabricated buildings as sheltered work space for the remaining technical operations. The two vans were designated the Rectifier Van[45] and the Copy Van.

When a suitable expansible van body was developed by the Corps of Engineers, development and testing proceeded for the final motorized sets of equipment (Fig. 38). The motorized train consisted of six basic van sections: cartographic,[46]

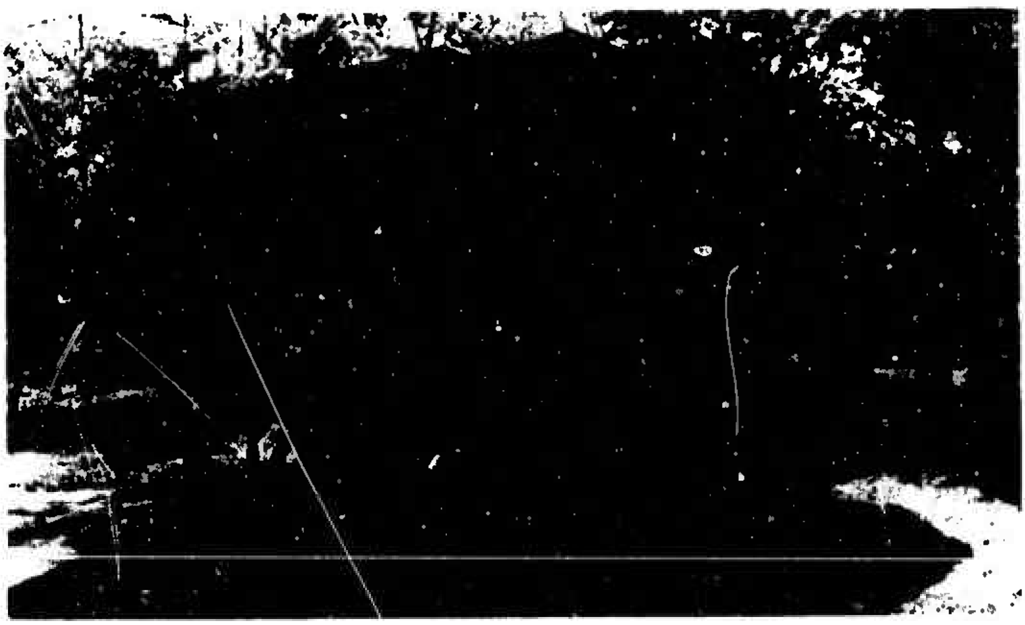

Fig. 38. Expansible van developed by the Corps of Engineers for the photomapping train.

42. "Multiplex Equipment, Motorized," ERDL Report 1233, 29 May 1952.

43. "Expansible Van Body (Engineer)," ERDL Report 1264, 14 November 1952.

44. "Engineering Tests of the Cartographic Van of the Army Topographic Battalion and the Corps Topographic Company and the Supply Van of the Army Topographic Battalion," ERDL Report 1267, 1 December 1952.

45. "Interim Solution Rectifier Van," ERDL Report 1355, 15 June 1954.

46. "Engineering Tests of the Cartographic Van Section of the Motorized Photomapping Train," ERDL Report 1373, 3 September 1954.

rectifier, multiplex, compilation,[47] copy and supply,[48] and map revision.[49] The Battalion train consisted of 11 vans: one rectifier, one multiplex, one copy and supply, two cartographic, two map revision, and four compilation. The Corps train consisted of five vans: one copy and supply, one cartographic, two compilation, and one rectifier. Final drawings and specifications and proposed set listings were completed in 1958.

(4) Mapping from High Altitude Photography. Current and anticipated trends toward higher altitudes in aircraft and antiaircraft defenses at the close of World War II led to a program in April 1947 to determine ways and means to make satisfactory topographic maps from very high altitude photography. Up to that time, the nominal altitude for mapping photography was around 20,000 feet, and an altitude above 30,000 feet was considered very high.

Early in these investigations, a test map was made with the multiplex equipment using photography flown at a 40,000-foot altitude. This test demonstrated the inadequacy of the multiplex;[50] the accuracy requirements for large scale maps were not met. This along with other investigations indicated that reliable identification of cultural detail for a large-scale map would require photography at a minimum scale of 1:30,000.[51]

To meet this requirement, the concept of simultaneous supplemental coverage with a long focal length camera assemblage along with the basic mapping coverage with the 6-inch focal length, wide-angle camera developed.

Accuracy of compilation, particularly contouring, was another facet of the problem. Accuracy investigations included an evaluation of the Kelsh Plotter[52] and comparative tests and evaluation of the Multiplex, Kelsh Plotter, Stereoplanigraph, Wild Autograph, and Wild Stereoplotter.[53] [54]

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47. "Combined Engineering and Service Test of the Photomapping Van Section of the Motorized Photomapping Train," ERDL Report 1428, 27 September 1955.

48. "Combined Engineering and Service Test of the Copy and Supply Van Section of the Motorized Photomapping Train," ERDL Report 1444, 27 April 1956.

49. "Combined Engineering and Service Test of the Map Revision Van Section of the Motorized Photomapping Train," ERDL Report 1447, 23 May 1956.

50. "Compilation and Evaluation of Topographic Maps and Controlled Mosaics Prepared from 40,000 Foot Altitude Photography of Fort Sill, Oklahoma," ERDL Report 1173, 28 June 1950.

51. "Investigation of Photographic Requirements for Mapping from High Altitude Photography," ERDL Report 1205, 4 June 1951.

52. "Investigation and Evaluation of the Kelsh Plotter," ERDL Report 1191, 10 April 1951.

53. "Comparative Tests and Evaluation of Multiplex, Kelsh Plotter, Stereoplanigraph, Wild Autograph Model A-5 and and Wild Stereoplotter Model A6," ERDL Report 1235, 30 May 1952.

54. "Comparative Aerotriangulation Tests of the Multiplex, Kelsh Plotter, Stereoplanigraph, Wild Autoplanigraph Model A-5, and Wild Stereoplotter Model A-7," ERDL Report 1349, 23 April 1954.

Studies were also made of the effects of earth curvature and atmospheric refraction.[55] In addition, an investigation was made of stereophotogrammetric mapping systems, including multiple-camera convergent systems,[56] to determine the potential advantages and limitations for the production of military topographic maps from high-altitude photography. These investigations led to a project to develop equipment and techniques for convergent photography use.

Investigations up to the mid-1950's were primarily oriented toward mapping with photography in the altitude range of 40,000 to 50,000 feet since test photography could be obtained in this range. Mapping photography of excellent quality was then successfully obtained from a balloon at about 89,000 feet. This removed the conjecture in some quarters that atmospheric haze would severely limit the quality of photography at these altitudes and higher, and studies were initiated to determine ways to prepare large-scale maps from photography taken at altitudes up to 100,000 feet. These studies resulted in the proposal of a system using 18-inch convergent cameras and a corresponding projection-type stereoplotter.[57] To test the system, 12-inch cameras were modified to simulate very high-altitude photography, and a projection plotter was modified to accommodate the 12-inch photography for test compilation.

(5) Autofocusing Reflecting Projector. Experience in World War II showed that the vertical reflecting projector, which projected photographs onto a map manuscript to transfer and compile detail, was a valuable item in the complement of compilation equipment. The commercial projectors then available were large and heavy and suitable only for a base plant installation. At the close of the War, development of a portable reflecting projector suitable for installation and operation in a truck or trailer was initiated.

This development pursued a normal course without major difficulty or delay and resulted in the development of the Autofocusing Reflecting Projector[58] which was standardized in September 1951 (Fig. 39).

The experimental model of this instrument was constructed by Reed Research, Inc., Washington, D. C., and was delivered to ERDL in March 1948.

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55. "Effects of Earth Curvature and Atmospheric Refraction Upon Measurements Made in Stereoscopic Models of High Altitude Photography," ERDL Report 1242, 9 July 1952.

56. "Study of Stereophotogrammetric Systems for Topographic Mapping With Very High Altitude Photography," ERDL Report 1352, 14 June 1954.

57. "A Proposed Stereophotogrammetric System for Topographic Mapping From Photography Taken at Altitudes up to 100,000 Feet," ERDL Report 1518-TR, 1 April 1958.

58. "Development of Portable Autofocus Reflecting Projector," ERDL Report 1212, Final Report, 24 August 1951.

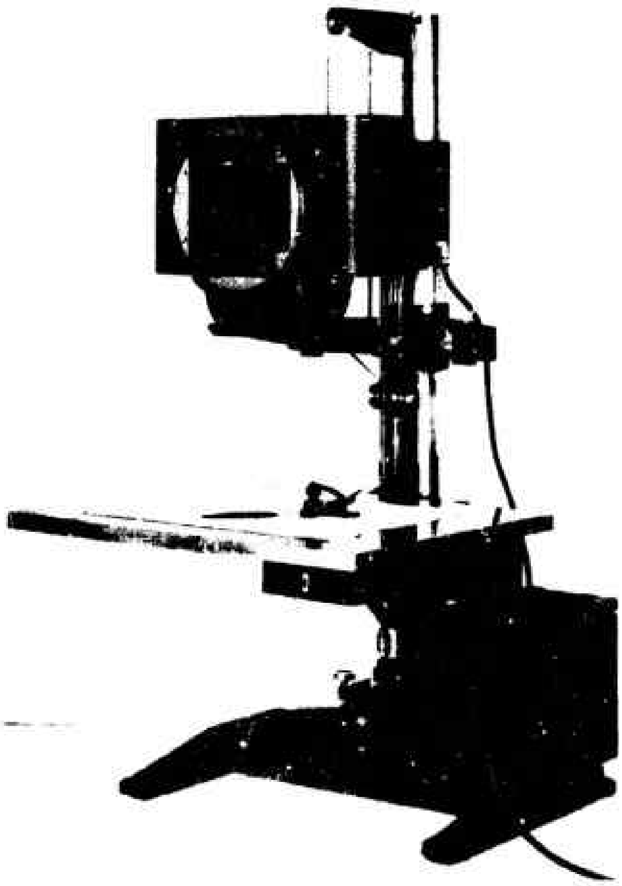

Fig. 39. Autofocusing Reflecting Projector.

Service tests were conducted by the 656th Topographic Battalion, Fort Belvoir, Virginia, and by the Air Force at Eglin Air Force Base, Florida.

(6) **Mirror Stereoscope.** An unsuccessful project was the development of a new mirror stereoscope with magnifying attachments designed for general stereoscopic viewing of 9-inch by 9-inch photographs. The project was initiated by the Army Air Forces who requested that the Corps of Engineers develop a new stereoscope incorporating the better features of other instruments and eliminating the undesirable features of the present model.

A contract was awarded to Harrison C. Ryker, Inc., in December 1947 for the design and fabrication of a stereoscope with interchangeable binocular magnifying attachments for 2- and 3-power magnification. After repeated delays by the contractor, who was having difficulty in designing the optical systems, the contract was cancelled at no cost to the Government.

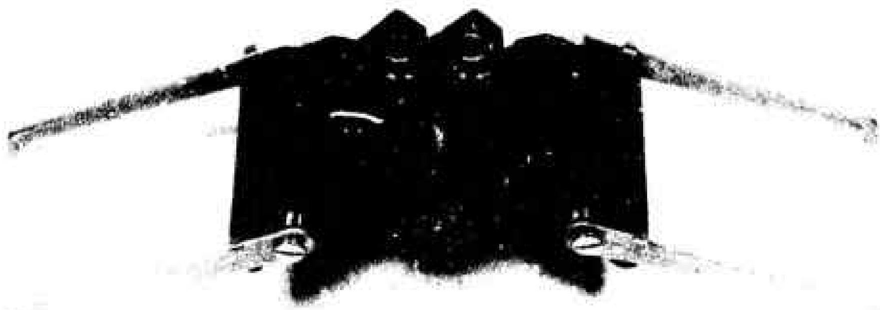

Fig. 40. Experimental improved mirror stereoscope with binoculars.

In December 1950, a contract was awarded to the Fairchild Camera and Instrument Corporation to design and fabricate engineer and service test models (Fig. 40). The engineer test model conformed to the military characteristics when tested by ERDL in October 1952.[59] The service test models were shipped to service test agencies in January and February 1953 as follows: Air Proving Ground, Eglin Air Force Base, Florida; Photographic Reconnaissance Laboratory, Wright-Patterson Air Force Base, Dayton, Ohio; Marine Corps Supply Depot, Camp Lejeune, North Carolina; U.S. Naval Photographic Interpretation Center; AFF Board 2, Fort Knox, Kentucky; AFF Board 1, Fort Bragg, North Carolina; and Army General School, Fort Riley, Kansas. The service test agencies almost universally rejected the mirror stereoscope as not operationally suitable or not a suitable replacement for the present stereoscope.

The Chief of Army Field Forces requested a comparative evaluation of the Old Delft stereoscope manufactured by the Old Delft Company, Netherlands. Four of these instruments were procured for evaluation, and the ERDL test[60] concluded that the Old Delft stereoscope had some highly desirable features but that it did not conform to the military characteristics of the project. The project was closed in 1954.

(7) **Portable Plotter.** Efforts began during World War II to find a suitable portable stereoscopic plotting instrument which would be superior to and replace the stereocomparagraph in field unit equipment sets and continued in the post-war period. In February 1948, a project was approved to develop such an instrument.

In this program, various stereoplotters were tested which were considered to be in the portable stereoplotter class: a Soil Conservation Service map plotter,

59. "Engineering Test of Mirror Stereoscope," ERDL Report 1260, 8 December 1952.

60. "Final Report Development of Mirror Stereoscope," ERDL Report 1382-TR, November 1954.

a KEK plotter, a stereotopograph developed by Fairchild Camera and Instrument Corporation, and the Ryker PL-3 Plotter produced by Harrison C. Ryker, Inc., Oakland, California.[61] [62] [63] Of these, the Ryker PL-3 Plotter was found to be more accurate and to conform to the military characteristics with minor exceptions. Service tests by the U.S. Air Force, the Army Field Forces, and the U.S. Marine Corps were begun early in 1953. Both the Marine Corps and the Air Force found the Ryker Plotter satisfactory and suitable for their use. The CONARC service test[64] however, concluded that the portable plotter was not suitable as a replacement for the stereocomparagraph and that further research was required to supplement the nonportable stereoplotter.

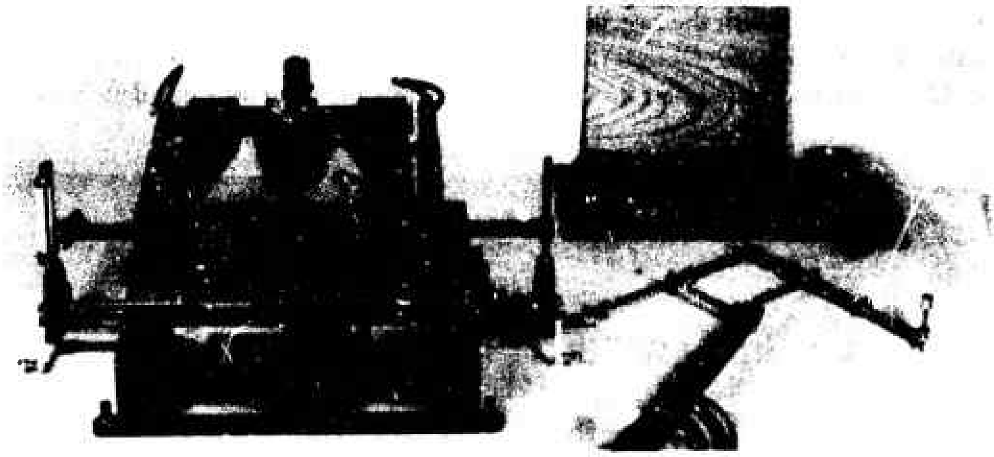

Fig. 41. The Model PL-3 Ryker Plotter – Wernstedt-Mahon type.

ERDL continued the research by testing an improved version of the Ryker Plotter, called the Wernstedt-Mahon Stereoplotter (Fig. 41), and a pilot model stereotope developed in Germany. However, by this time, efforts to motorize the multiplex equipment had progressed to the point where a multiplex van section had been developed for the motorized photomapping equipment train and a portable plotter was no longer needed. Therefore, in February 1957, a final technical report[65] on this project was published. It noted the suitability of the Wernstedt-Mahon Type Plotter for the Marines and the Air Force but that CONARC did not consider the plotter a suitable replacement for the stereocomparagraph. The report concluded that no further

61"Soil Conservation Service Topographic Map Plotter," Engineer Board Report 15 February 1944.

62"Comparison of the Stereotopograph and the KEK Plotter," ERDL Report 1014, 15 September 1947.

63"Investigation of the Ryker PL-3 Plotter," ERDL Report 1129, 17 June 1949.

64"Stereoplotter Topographic Portable," CONARC Report 1728, Report of Project No. 1728, 17 May 1955.

65"Test and Evaluation of the Direct Viewing Stereoplotter Wernstedt-Mahon Type," ERDL Report 1471-TR, 27 February 1957.

attempts should be made to develop a portable stereoplotter for mapping from near-vertical photography. The project was cancelled in July 1957.

(8) **High Precision Stereoplotter.** The project on the high precision stereoplotter was approved in January 1951 to provide suitable equipment to compile topographic maps from photography taken at all practicable mapping altitudes up to 50,000 feet. The first phase objective was to determine which commercially available equipment most nearly met the military characteristics and was suitable for base plant use for immediate emergency procurement.

Both the Instruments Corporation Model 5000 Kelsh Stereoplotter[66] and the Bausch and Lomb Optical Company Model 720 Stereoplotter[67] were tested (Fig. 42). It was concluded that the Model 5000, with correction of some deficiencies

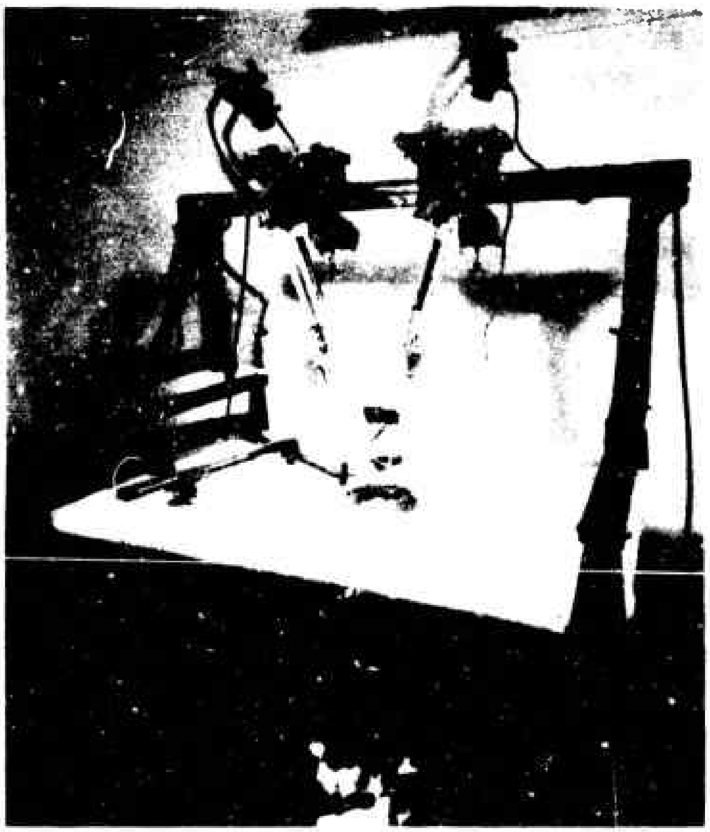

Fig. 42. The Bausch and Lomb 720 Stereoplotter.

[66] "Test and Evaluation of the Kelsh Plotter, Model 5000, Manufactured by the Instrument Corporation," ERDL Report 1311.

[67] "Test and Evaluation of the 720 Plotter Manufactured by the Bausch and Lomb Optical Company," ERDL Report 1348, 23 April 1954.

found in the tests, would be suitable for interim emergency procurement. The model 720 was not considered as an interim item since it was not commercially available. A military specification, MIL-S-12623A, "Stereoplotter, Projection Type, Topographic, with Table and Cases," was prepared for emergency procurement.

A development contract was awarded to the Kelsh Instrument Company in September 1954 to develop an instrument to be called the Stereoplotter, Convergent, Vertical. This was to be the military model of the high-precision stereoplotter and was designed to use both vertical and convergent photography at high altitudes. While this instrument was being developed, an interim stereoplotter conforming to MIL-S-12623A was procured for test by ERDL.[68] In addition, the Balplex equipment manufactured by the Bausch and Lomb Optical Company was procured on loan for test and evaluation. (This was the same item as the U.S. Geological Survey ER-55 Stereoplotting Equipment.)

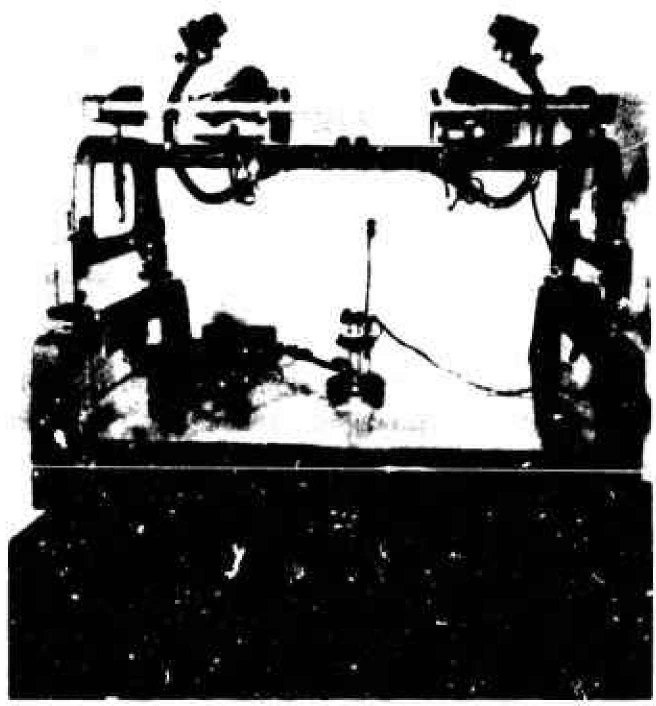

Fig. 43. High-Precision Stereoplotter.

ERDL Report 1493-TR concluded that the plotter conforming to MIL-S-12623A most nearly met the military characteristics and was suitable for base plant use (Fig. 43). The accuracy ratio of the interim plotter to the multiplex was

[68] "Test and Evaluation of Interim Stereoplotter, Topographic, Projection Type High Precision," ERDL Report 1493, 8 August 1957.

approximately the same as the ratio of the viewing scales of the two instruments. On a square-mile basis, the time required for compilation and aerotriangulation was approximately the same for both the interim stereoplotter and the multiplex, and that no classification action should be taken pending the development of the high-precision military topographic plotter.

It was not until 1959 that engineering tests of the high-precision stereoplotter[69] developed under the Kelsh Instrument Company contract were completed, and it was recommended that type-classification action be taken without service testing.

(9) **Utilization of SHORAN for Mapping.** Late in World War II, investigations of the possibility of adapting SHORAN (Short Range Navigation) to establish horizontal control, thus eliminating much of the ground survey required for mapping, were initiated. In 1945 and 1946, the first SHORAN-controlled photographic tests were flown using equipment designed for bombardment operations but with a photographic distance recorder replacing the bombing computer. These early tests showed that even this bombing equipment would be suitable for establishing control in remote areas.[70] [71]

Between 1947 and 1950, data-reduction techniques and simple photogrammetric aids to application of the procedure (nadirscope, 35-mm film holder, floating stud holder) were developed[72] [73] [74] and in 1950, instructions for SHORAN photogrammetric mapping were issued.[75]

Investigations continued into the 1950's with the development of mathematical aids to SHORAN operational planning[76] in 1951. Further, in the early 1950's, the U.S. Air Force modified several bombardment-type instruments to improve precision. The modified equipment was called HIRAN to designate high precision. Additional testing and improvement of techniques were accomplished between 1953

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69. "Stereoplotter, Topographic, Projection Type, High Precision," ERDL Report 1627-TR, April 1960.

70. "Application of SHORAN to Mapping," ERDL Report 987, 29 August 1946.

71. "An Investigation of Control Point Photography in SHORAN Mapping," ERDL Report 1012, 1 September 1947.

72. "A Derivation of Simplified Formulas for Computing SHORAN Range and Path Height," ERDL Report 1106, 11 February 1949.

73. "Auxiliary Equipment for SHORAN Photogrammetric Mapping," ERDL Report 1110, 8 April 1949.

74. "An Investigation of Slotted Templet Methods in SHORAN Mapping," ERDL Report 1133.

75. "SHORAN Photogrammetric Mapping Instructions," ERDL Report 1168, 15 May 1950.

76. "Mathematical Aids to SHORAN Operational Planning," ERDL Report 1218, 28 September 1951.

and 1957. In June 1957, ERDL Report 1484-TR[77] concluded that maps compiled by multiplex methods using HIRAN-controlled photography met emergency map accuracy standards for 1:25,000 scale maps and national map accuracy standards for 1:50,000 scale maps.

(10) **Equipment and Techniques for Convergent Photography.** As previously noted, investigations of the problem of mapping with very high-altitude photography led to the concept of using convergent photography taken with a two-camera installation consisting of two 6-inch focal length, wide-angle precision mapping cameras tilted approximately 20° from the vertical, fore and aft, in the line of flight. Therefore, in 1954 a project was approved to develop equipment and techniques for convergent photography.

Over the next 5-year period, a number of items (Figs. 44 through 47) were developed and tested at ERDL, including the stereopontometer method of aerotriangulation using convergent photography and a projection type stereoplotter,[78] a transforming printer for restitution of the tilted photographs,[79] and graphical methods of mapping with convergent photography. Two attempts were made to develop a scanning-type stereoscope for viewing the transformed prints. The first, developed under contract by Reed Research Inc., proved too heavy. In addition, the mechanical scanning system was overly complex and did not achieve the desired simplicity.[80] Following this attempt, a contract was awarded to Maryland Precision Instruments Company for the manufacture of four improved scanning stereoscopes for service testing. They experienced considerable difficulty with optical subcontractors and were unable to deliver a satisfactory stereoscope.

By this time, interest in the use of convergent photography of this type, particularly by topographic field units, began to wane, so the service testing of the scanning stereoscope was cancelled.

Finally, ERDL Report 1583-TR[81] was published. This report concluded that convergent photography had a higher vertical accuracy potential and about the same horizontal accuracy as vertical photography and it was suitable for base plant

[77] "Evaluation of High Precision SHORAN Controlled Photography," ERDL Report 1484-TR, 13 June 1957.

[78] "Test and Evaluation of the Stereopontometer With Kelsh Type Stereoplotters," ERDL Report 1425, 7 September 1955.

[79] "Engineering Tests and Evaluation of the Photogrammetric Transforming Printer With 20-Degree Convergent Photography," ERDL Report 1497-TR, 28 August 1957.

[80] "Engineering Test of Scanning Stereoscope," ERDL Report 1491-TR, 7 August 1957.

[81] "Equipment and Techniques for the Utilization of Convergent Photography in Mapping," ERDL Report 1583-TR, 28 August 1959.

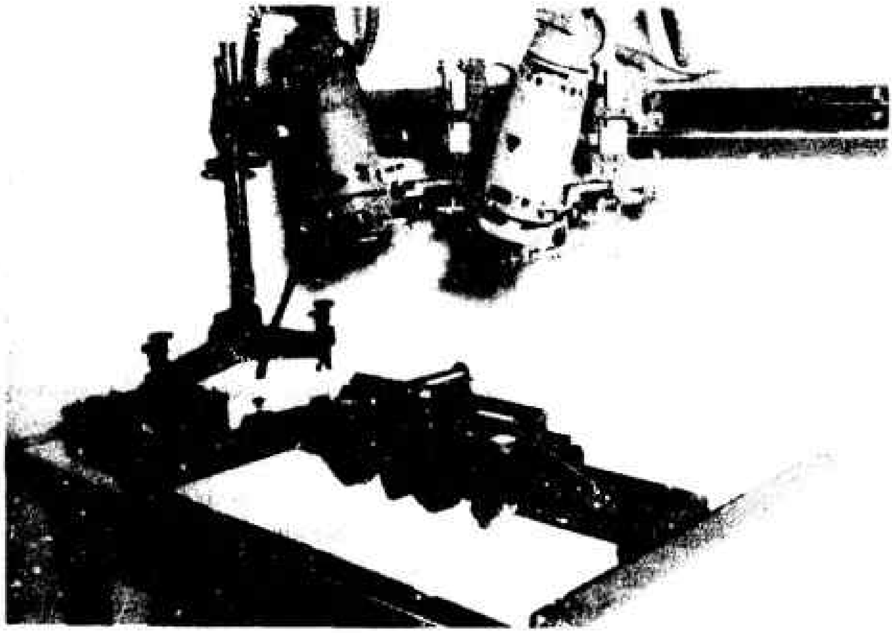

Fig. 44. Adapted multiple equipment with the stereopontometer for convergent photo aerotriangulation.

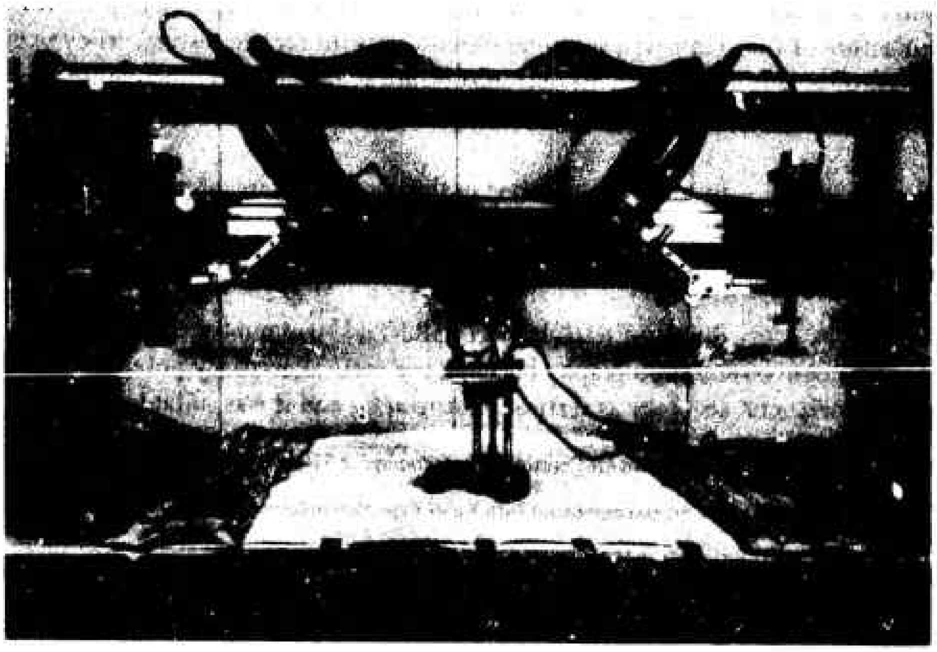

Fig. 45. Experimental multiplex setuᵖ for convergent photo compilation using the adjustable tilt bar.

Fig. 46. Experimental transforming printer for 20° convergent photography.

Fig. 47. Experimental scanning stereoscope designed for viewing transformed 20° convergent photos.

operations and should be fully exploited at the Army Map Service, especially during peacetime. However, field topographic units can seldom realize the inherent benefits of convergent photography. It was recommended that the project be terminated. It was terminated in 1960.

(11) Radar Mapping. A program of research and study into the use of radar presentations for topographic mapping was approved in August 1949. Such procedures would permit mapping from data gathered at night or through an overcast.

Initial studies[82] of airborne search radar application to mapping indicated that equipment available at the time would be suitable only for small-scale mapping because of limitations of position accuracy and map detail in radar scope photography. Research continued in the early 1950's on radar relief displacement, parallax, tilt displacement, etc. associated with PPI (plan position indicator) radar.[83] An instrument (Fig. 48) was designed and constructed to correct geometric distortions in the PPI

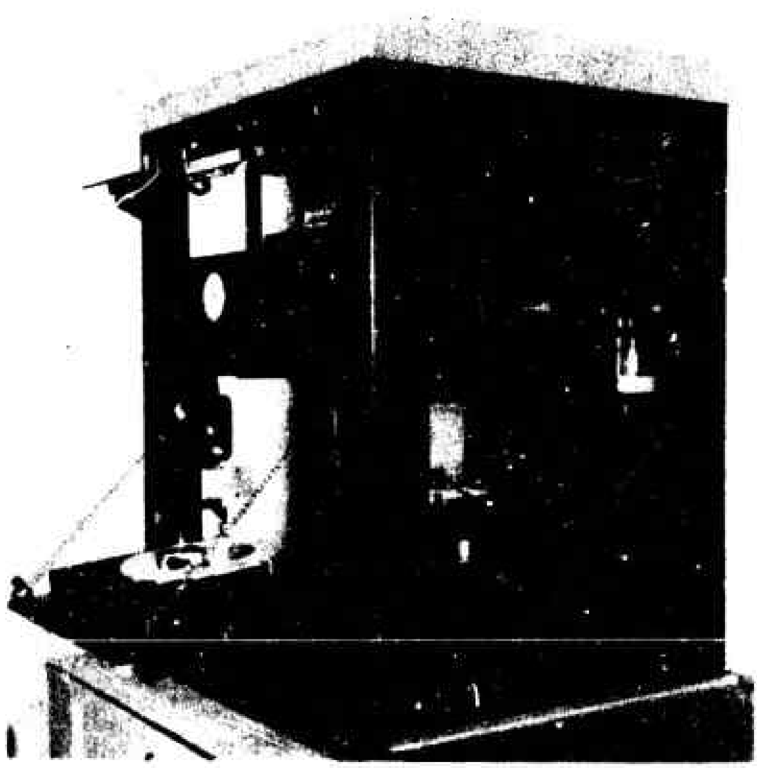

Fig. 48. PPI Radar Restitutor.

82. "Mapping From Radar Presentation," ERDL Report 1209, 1st Interim Report, 24 July 1951.

83. "Radar Relief Displacement and Radar Parallax," ERDL Report 1294, 12 May 1953.

presentation. The pilot model was constructed by Paul Rosenberg Associates under ERDL contract and was delivered in September 1952. Two engineering test model Radar Presentation Restitutors were developed by Fairchild Controls Corporation and delivered in December 1955. These instruments were capable of providing corrections to an accuracy of 4 parts per 1000 of the range of the PPI photographs.[84]

The status of radar mapping development in 1955 was reviewed in ERDL Report 1397.[85] At about this time, interest shifted to the use of side-looking radar. After tests with AN/APQ-45 and AN/APQ-56 radar photography and further investigation of these radars which indicated lack of geometric fidelity, it was determined that instrumentation necessary for converting geometry in side-looking radar presentations was feasible, provided the necessary auxiliary data was available.

Studies then began under contract with Northrop Aircraft, Inc., to determine equipment requirements and procedures for mapping and target location from radar scope presentations and to establish the requirements for an optimum system to use such presentations under combat conditions.

In 1958, concepts for the development of a radar sketchmaster were formulated; but, more significantly, coordination between the Corps of Engineers and the Signal Corps for a joint radar test program was initiated. By the end of 1959, plans for joint Corps of Engineers and Signal Corps radar tests were almost complete, and the initial requirements for developing an airborne radar mapping system had been coordinated with the U.S. Army Signal Research and Development Laboratories. Requirements for the development of a side-looking radar restitutor were also completed, a research contract was awarded to the Goodyear Aircraft Corporation for investigation of terrain elevation data from airborne radar, and the design of radar mapping test ranges had been completed under contract by the Aero Service Corporation.

(12) **Analytical Photogrammetry**. The development of analytical photogrammetric procedures for field and base plant use began in the mid 1950's. At that time, studies of mapping with minimum ground control indicated that analytical photogrammetry can be used under conditions of adjustment where there was an abundance of ground control as well as minimum ground control. Further, with the development of electronic data processing equipment, the formerly cumbersome and time consuming mathematical solutions could be completed quickly and accurately.

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[84] Robert P. Macchia, "Engineering Tests of the PPI Radar Presentation Restitutor," ERDL 1629-TR, May 1960.

[85] "Mapping From Radar Presentation," ERDL Report 1397, Second Interim Report, 25 April 1955.

Initial efforts to develop analytical photogrammetric procedures were made under contracts with Cornell University and Mr. Robert Zurlinden.[86] Under the Cornell contracts, programs were developed for the AMS Univac I and for the IBM 650 which included a generalized procedure for block adjustment using all applicable airborne and ground control in a simultaneous adjustment. Under the Zurlinden contract, the basic designs of a combined analog-analytical method of aerial triangulation, adaptable for use with convergent photography as well as nearly vertical were developed. Unlike the Cornell methods, which required a large scale computer, the method of Mr. Zurlinden was adaptable to a general-purpose, small-scale computer. The Zurlinden method was an overall system approach to analytical triangulation and included the design of three instruments for determining photographic coordinates—an enlarging camera, a pass point selecting and marking instrument, and a measuring instrument (Fig. 49). These were subsequently built for test.

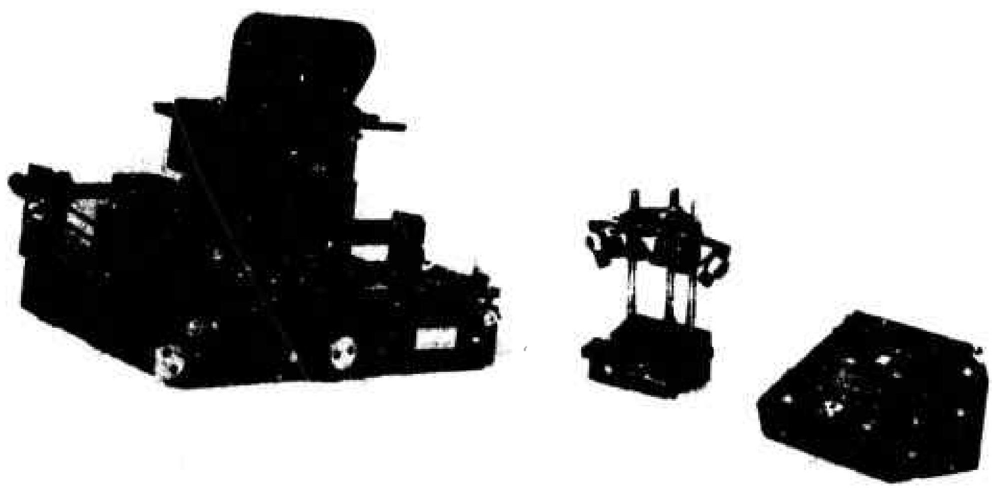

Fig. 49. Zurlinden equipment for analytical photogrammetric procedures: enlarging camera, pass point selecting and marking instrument, measuring instrument.

Point marking and coordinate measurement for analytical triangulation were serious limitations to successful application of these procedures in the late 1950's, even to the extent that ERDL reconditioned an old foreign made Stienheil stereocomparator for test purposes. Following an extensive search for a commercial stereocomparator, a Nistri Model TA-3, manufactured in Italy, was procured. The Mann monocomparator was also used in triangulation experiments.

By 1960, an optimized program for the general solution of analytical aerial triangulation was nearing completion, and a program for small computer

86. "Analytical Aerial Triangulation," ERDL Report 1510-TR, 13 March 1958.

application was ready for test and evaluation. Plans were being made for the design and construction of a semiautomatic electronic pass point measuring, marking, and recording instrument.

(13) **Automatic Map Compilation.** ERDL began development of automatic map compilation in 1950 under a project for the development of terrain model production methods. In May 1950, a contract for basic research on a scanning device was awarded to the Bausch and Lomb Optical Company, Rochester, New York. This research was to determine and demonstrate, if practicable, whether an instrument could be built to locate automatically and rapidly the consecutive positions of terrain points in a three-dimensional optical model. It was also to determine if the position of these terrain prints could be transmitted to a machine that would use this information to produce a three-dimensional terrain model, a contour map, a point-to-point scale corrected mosaic, or a combination (Fig. 50). By April 1952, this contract was completed and the possibility of developing instrumentation for automatically producing three-dimensional maps was successfully established.

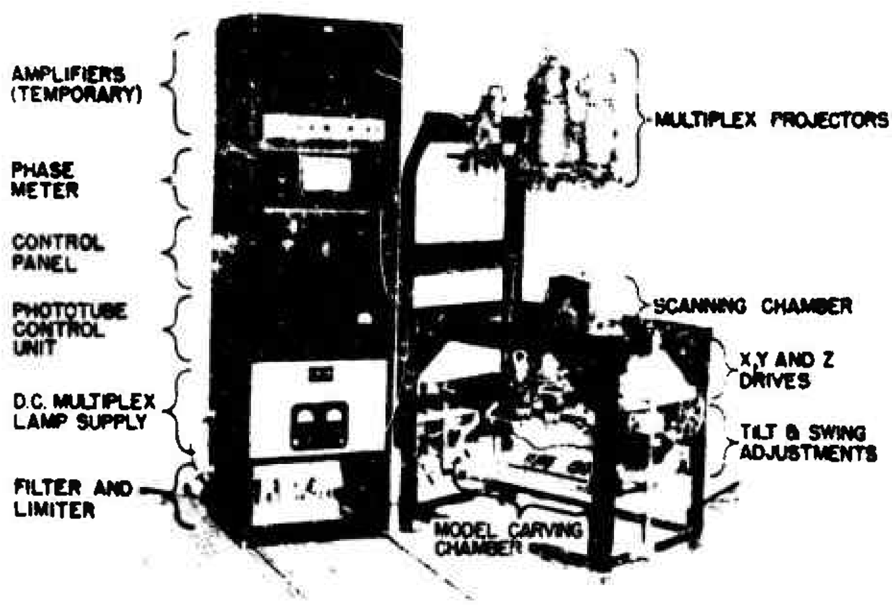

Fig. 50. Experimental automatic profile carving equipment developed under Bausch and Lomb Optical Company contract, 1951.

The basic engineering problems involved appeared to be electronic, concerned with correlation methods and optical-to-electrical transducers suitable for determining the intersection of conjugate rays in an optical stereoscopic model. A contract was awarded to Pickard and Burns in June 1952 to investigate these problems (Fig. 51). Progress on this contract was rather discouraging, but finally in late 1954 the work had

Fig. 51. Experimental automatic profile carving equipment as modified by Pickard and Burns, 1954.

progressed so that scanning the multiplex stereo model of an artificial cone produced a plot of points of indicated conjugate ray intersection in which the faint pattern of contour lines could be distinguished.

Based on the analysis of the equipment developed by Pickard and Burns, negotiations were initiated in 1955 to develop an instrument to contour automatically models projected by a Kelsh-type stereoplotting instrument. This negotiation resulted in the award of a contract to Hycon Manufacturing Company for the delivery of an Automatic Contour Plotter, Hycon Model 545, which was developed by that company (Fig. 52). The effort proved to be totally unsuccessful. The Hycon instrument failed to perform as required and the contract was closed. The government purchased the hardware and retained a royalty free license to any patent that may be granted for the instrumentation.

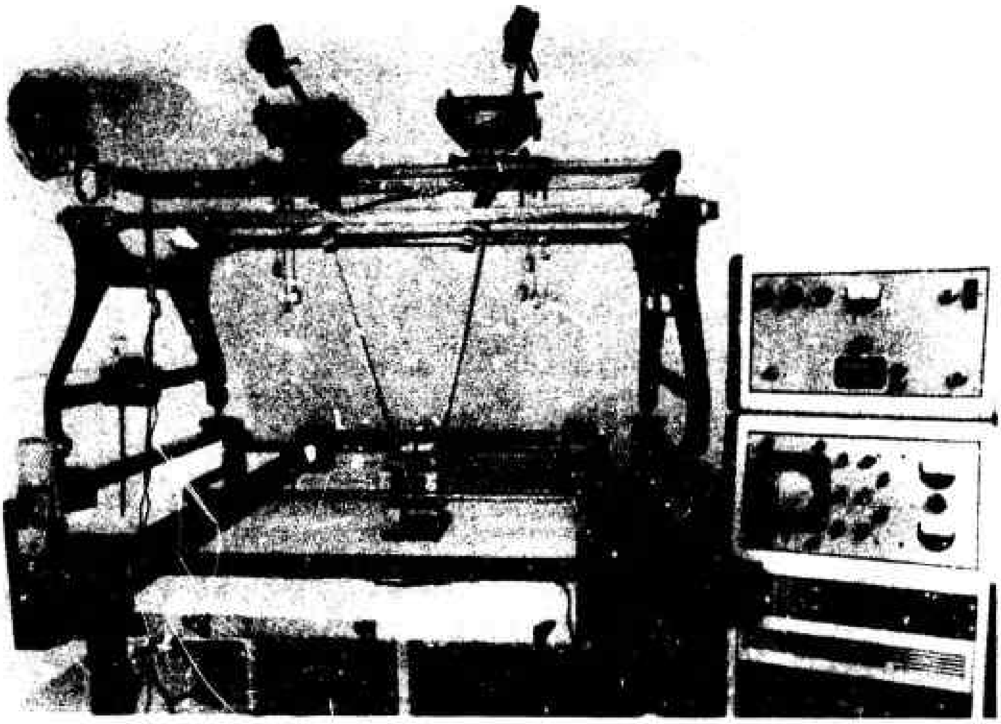

Fig. 52. Hycon Automatic Contour Plotter, 1957.

This effort was continued by a contract to Hogan Laboratories for the design and construction of equipment to traverse the model and to scan the two stereo projected images mechanically using the Hycon equipment as a basis. The assembly built by Hogan Laboratories was eventually delivered to ERDL in June 1959, and when tested it failed to perform as required. However, modification and improvements were made in-house at ERDL, and this modified equipment did indicate the feasibility of an automatic stereomapping system based on a mechanical scanner. Therefore, at the beginning of the 1960's, after almost 10 years of development effort, detailed specifications had been developed for an automatic mapping system based on a mechanical scanning system, and preparations were being made to contract for its construction.

While the mechanical scanning approach was proving to be the most satisfactory in ERDL efforts to automate the location of conjugate imagery, another approach was under development at the Photographic Survey Corporation of Canada by Mr. Gilbert G. Hobrough who automated the contouring function of a Kelsh plotter in 1956. In this equipment, initially called the "Auscor" for automatic scanning and correlation and later the "Stereomat," the electronic image scanning of the projected diapositives was accomplished by a flying spot scanner located in the position of the standard tracing table platen (Fig. 53). Rights to this development were obtained by the

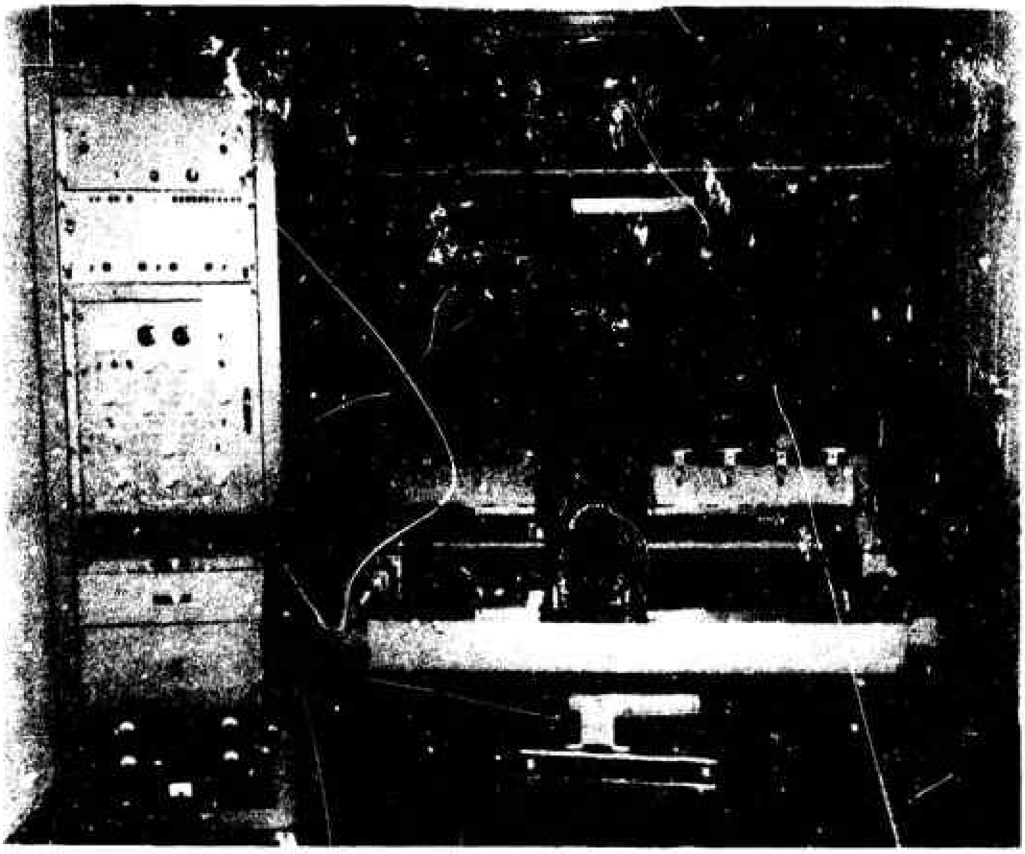

Fig. 53. Automatic stereomapping system employing the Hobrough electronic image scanning, 1959.

Benson Lerner Corporation, Los Angeles, California; and in May 1959, ERDL contracted with Benson Lerner Corporation for a prototype Stereomat. This instrument, using a Nistri photomapper as the projection stereoplotter, would automatically determine the components of parallax in a projected stereo model and in this manner provided for the automatic orientation of the stereoscopic model and automatic contouring by the line-drop techniques.

Research in automatic mapping concerned with applying information and systems theory to the flow of data through a photogrammetric mapping process was started with a contract awarded to Paul Rosenberg Associates in 1953. Under this and subsequent research contracts with Paul Rosenberg Associates, several concepts for automatic mapping were formulated. One of these concepts used conventional aerial negatives and control information to output a contoured orthophotograph. In operation, the system would scan the negatives, determine the correct elevation of all ground points, and compute the correct photocoordinates. This data would be recorded on

tape which would subsequently control the operations of an automatic orthophoto printout unit. Another concept would perform all the functions of the one described above and also provide an automatic control bridging solution for the aerial flight strip. The most sophisticated of the concepts formulated would be the most completely automatic. In this system, the conventional aerial photography would be bypassed by a direct terrain line scan system, converting the terrain information to an electrical signal or magnetic tape with subsequent processing to produce a contoured orthophotograph. The first of these concepts was obviously the easiest to implement and was consequently the approach pursued in subsequent developments, based upon integrating flying spot scanners and electronic correlation with a digital computer for computation and control.

While automatic mapping developments were beginning to provide practicable production instrumentation in the late 1950's, the Army Map Service, without waiting for these developments to mature, came up with a requirement for a semi-automatic map compilation system. Under the direction of the Office Chief of Engineers, in 1958 a contract for this "Integrated Mapping System" was awarded to the Fairchild Camera and Instrument Company, Syosset, New York. This equipment, subsequently modified under contract with the Atlantic Research Corporation, Alexandria, Virginia, was eventually completed for test in the early 1960's. It used a Nistri Photomapper and required an operator to raise and lower the tracing table manually while the instrument was driven at a selectable speed, transversing the model. Each profile was temporarily recorded on magnetic tape. This tape would then be checked and recorded in three forms simultaneously or independently: line-drop contour manuscript, orthophotograph, and a permanent tape recording. During each subsequent profile, the temporarily stored profile information was used to position approximately the height of the tracing table platen, thus providing an operator assist in following the new profile.

While this equipment was not economical or efficient, it did serve as a convenient testbed for procedures independent of electronic correlation. It first demonstrated the feasibility of the line-drop technique for contouring, the feasibility of producing an orthophotograph electronically, the digital recording of profile information, and the applicability of the previous profile assist.[87]

(14) Mapping with Minimum Ground Control. Throughout the 1950's and into the 1960's, the development of techniques and photographic requirements for mapping inaccessible areas with little or no ground control held a relatively high priority in the Corps of Engineers research and development program. While the post World War II development of SHORAN and related techniques provided an approach to the establishment of horizontal position and scale, the vertical was still a problem.[88]

[87] Reuben D. Cook, "Engineering Test Report of the Integrated Mapping System," GIMRADA TR-7, July 1962.

[88] "Contouring Inaccessible Areas Having Limited Vertical Control," ERDL Report 1107, 4 March 1949.

Initial investigations in the early 1950's with the photogrammetric tests and development performed by the Army Map Service concerned the use of recorded barometric altimeter data alone and in combination with radio altimeter data for scaling and leveling. These investigations resulted in the development by 1952 of multiplex procedures to use airborne altimeter recordings. Further tests made under contract by the Photographic Survey Corporation, Ltd, Canada, in 1952 confirmed the value of applying aneroid and airborne profile recordings.

Later, interest developed in the application of simultaneous aerial photography and airborne profile recording data. Extensive investigations and tests were made under contract by Lockwood, Kessler, and Bartlett, Inc., in 1955 and 1956 and also by the National Research Council of Canada in 1957. The Lockwood, Kessler, and Bartlett investigation indicated appreciable accuracy deficiencies when the method was applied in an area of approximately 1000 square miles. It also indicated that the procedures were too complex for use by field topographic units. ERDL therefore worked to further simplify the procedures and improve the accuracy of results.[89]

The next major phase in this development was an investigation of long-distance aerotriangulation with the award of a contract to Jack Ammann, photogrammetric engineer, in late 1957 to perform 100 model triangulation tests with a first-order precision instrument. This contract was modified in 1959 to include triangulation tests using convergent photography. Early in the test program, after the first of three 100 model triangulations were completed, the general conclusion was drawn that bridge solution would yield more reliable results than the cantilever and that the use of 10 models as a basis for a 90-model cantilever extension would not result in a reliable extension.

In 1958, investigations began on the use of two aircraft on adjacent flight lines to obtain pairs of simultaneous stereophotographs with the airbase of each stereo pair determined by a radar measurement of the aircraft separation at the instant of exposure. The known airbase would provide direct information for establishment of scale and the vertical datum would be established from airborne profile recorded data obtained by each aircraft. In 1959, a contract was awarded to Fairchild Aerial Surveys, Inc., for test and evaluation of this approach. In 1958 a contract was also awarded to Abrams Aerial Survey Corporation for an investigation of the Santoni solar method of aerial triangulation. In 1959, a contract was awarded to the Autometric Corporation for an analysis of the accuracy of area matching with aerial photography, an approach that accomplishes aerotriangulation by measuring between aerial photographs through matching their images electronically. It is based on the hypothesis that all displacements in the photograph, such as those due to tilt and ground relief, are random and

89. "Mapping With Minimum Ground Control," ERDL Report 1483-TR, 13 June 1957.

therefore their mean positions determined statistically are more accurate than those obtained from individual photographs.

At the close of the 1950's, the development of techniques for mapping in areas with little or no ground control was still active and the program included at that time the investigation of the dual aircraft system, the Santoni solar methods of aerial triangulation, the long distance triangulation, and the area matching techniques.

(15) **Research for Map Compilation.** In the early 1950's use of very high-altitude photography was being investigated and work had begun on equipment and techniques for the use of convergent photography in mapping. It became apparent that there was a lack of knowledge concerning the basic factors which contributed to or limited the accuracy of measurement in stereophotogrammetric processes. A research program was therefore implemented to develop a better understanding of these basic factors to determine where research and development effort should be concentrated to provide adequate maps from high-altitude photography.

The first efforts under this program, started in 1952 and continuing into 1955, were a series of studies by the Ohio State University Research Foundation. These included the influence of errors of interior and relative orientation, the effects of errors in calibration of the mapping camera, the influence of errors of absolute orientation, methods of determining primary observational errors, and the theory of errors for relative orientation of convergent photographs.

Research continued at the Ohio State University Research Foundation in 1955 and 1956 with investigations of least-squares methods of aerotriangulation adjustment as compared to instrument triangulation with conventional methods of adjustment. Surprisingly, the least-squares method was found to be less accurate and more time-consuming than the conventional method when applied to strips of vertical photography with terminal control and one intermediate control band.

In 1956, a study of visual stereoscopic acuity under a wide range of viewing conditions was initiated under contract with the University of Rochester. In addition, a contract was awarded to Fairchild Camera and Instrument Corporation to determine the repeatability of calibrating equipment and operating techniques then employed by this contractor in calibrating mapping cameras for the Air Force. These investigations continued through 1957 and provided experimental data on which to base future equipment and technique development.

In 1957, with the imminent availability of aircraft operating at supersonic flight speeds, an investigation began on the effects of environmental conditions caused by supersonic flight speeds upon the geometric characteristics of aerial photography.

In 1958, after the first artificial earth satellite was launched and in view of military operational concepts involving missiles with increased capabilities and mobility, accurate topographic maps of extensive areas and rapid means for locating positions of targets became increasingly important. Since existing methods required excessive time and could handicap strategic and tactical planning when unexpected operational changes occurred, a greatly expanded research program was implemented. It had supplemental funding to determine new criteria, phenomena, facts, principles, or techniques applicable to mapping methods or equipment. Under this expanded program, a study was contracted to Vidya, Inc. in 1959 to study the deleterious effects on mapping photography caused by environmental conditions of supersonic speed, This study provided a theoretical analysis of the problem, including the parameters of aircraft configuration and location of camera in the aircraft. More important, a study contract was awarded to New York University to research instrumentation and techniques for precise surveying, mapping, and target location using satellite data as well as data obtained with other vehicles – both supersonic and hypersonic. This study continued into 1960 and produced a series of quarterly reports in which various problems associated with satellite supersonic and hypersonic vehicles were analyzed and techniques for exploitation were suggested. For this program and other research programs in the surveying and geodesy field which will be described later, arrangements were made with the University of Maryland to furnish an advisory team to assist ERDL in periodic review of the research and guidance of the effort. The advisory team included Dr. Sanford Goldman of Syracuse University, an expert on electronics, Dr. Paul Herget, Director of the Cincinnatti Observatory, an astronomer and specialist in celestial mechanics and developer of the Herget method of aerotriangulation, and Professor Frederick J. Doyle of Ohio State University, a specialist in photogrammetry, surveying, and geodesy.

(16) Miscellaneous Investigations.

(a) Precision Globes and Spherical Map Sections. Of historical interest is a project on precision globes and spherical map sections which was conducted in 1952 by the Committee on Construction and Use of Precise Globes and Spherical Maps, formed under the Geological and Geographic Division of the National Research Council. It was assigned to the Corps of Engineers by the Research and Development Division of the Office of the Assistant Chief of Staff, G-4, on the basis that a gap existed in the area of basic research of undistorted maps of the earth surface (possibly on a spherical surface).

At the outset of the program, a contract was awarded to the National Academy of Science to provide technical and program guidance to the project and for three technical investigations: (a) a study of basic map sources and related data available for the compilation of accurate globes, (b) determination of present day

methods of fabrication and study of all pertinent data for producing globes and spherical map sections, and (c) a study of present and potential user requirements.

In 1953, funds were transferred to the Rock Island Arsenal for the design and construction of two 63.45-inch diameter accurate spheres and maps (1:15,000,000 scale). At ERDL, eight prototype spherical sections of reinforced polyester resin were produced. These sections were nearly equilateral spherical quadrilaterals, about 30 square feet in area, representing any section from a 1:1,000,000 sphere.

In 1955, a 1:1,000,000 map of the world from southern and western South America was mosaicked on the prototype spherical map sections. The Army Map Service and the Rock Island Arsenal determined that it would be extremely difficult and expensive to apply multicolor cartographic data to the precise spheres by any method other than hand scribing and etching. This ended the development effort and the project was terminated in 1956 in view of the lack of a military requirement and the estimated expense of production of accurate globes.[90]

(b) **Multiplex Short Frame.** In the period from 1948 to 1952, including a 2-year suspension of the project from 9 February 1949 to 2 February 1951, a short-frame multiplex set (Fig. 54) was developed by the Engineer Board.[91] This set provided a way to plot individual multiplex models which was smaller, lighter, less costly, and required less space for operation than the standard, single-frame set.

(c) **Multiplex Reduction Printer.** With the development of the nominally distortion-free Planigon wide-angle camera lens by the Air Force in the early 1950's, it became necessary to develop a multiplex reduction printer suitable for preparing diapositive plates from photography with either the 6-inch Metrogon or the 6-inch Planigon lens (Fig. 55). This was accomplished by the development of a distortion-free projection lens for the multiplex reduction printer and a negative hold down or pressure plate with an aspheric surface to be used when making diapositives from Metrogon lens photography. This was the first known application of the aspheric distortion compensation plate in equipment of U.S. manufacture. The development was approved 4 January 1952 and was completed in 1956.

(d) **Diapositive Processing Equipment.** A project was approved on 5 December 1952 to develop equipment suitable for troop use for the quantity production of high-quality diapositives for both the multiplex equipment and the high-precision stereoplotter then under development. Three items were developed under contract

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90. "Development of Spherical Map Sections and Transparent Conforming Overlays," ERDL Report 1440, 5 March 1956.

91. "Instruments, Plotting, Stereoscopic, Multiplex, Set No. 7, Short Frame," ERDL Report 1243, 15 July 1952.

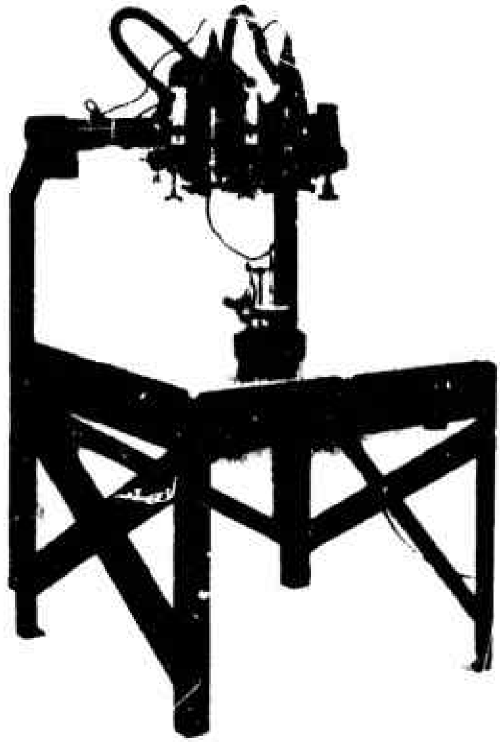

Fig. 54. Short-Frame Multiplex Set.

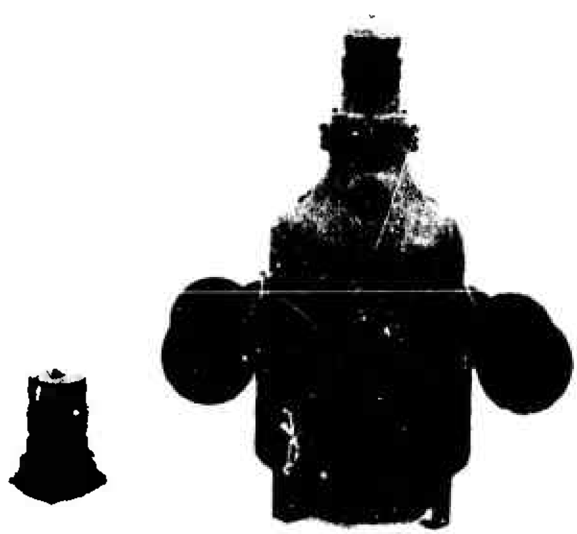

Fig. 55. Multiplex Reduction Printer with interchangeable hea[illegible] [illegible]r metrogon and planigon lens photography, developed in the mid-[illegible]0's.

in 1953: (a) diapositive processing unit, (b) exposure and doging control equipment for the multiplex reduction printer, and (c) a contact printer (point light source type) for 9½-inch aerial roll film with exposure and dodging control.

The first diapositive processing unit produced under contract (Fig. 56) failed in test, and it was necessary to contract for a second model, thus delaying completion of this project until the early 1960's.[92]

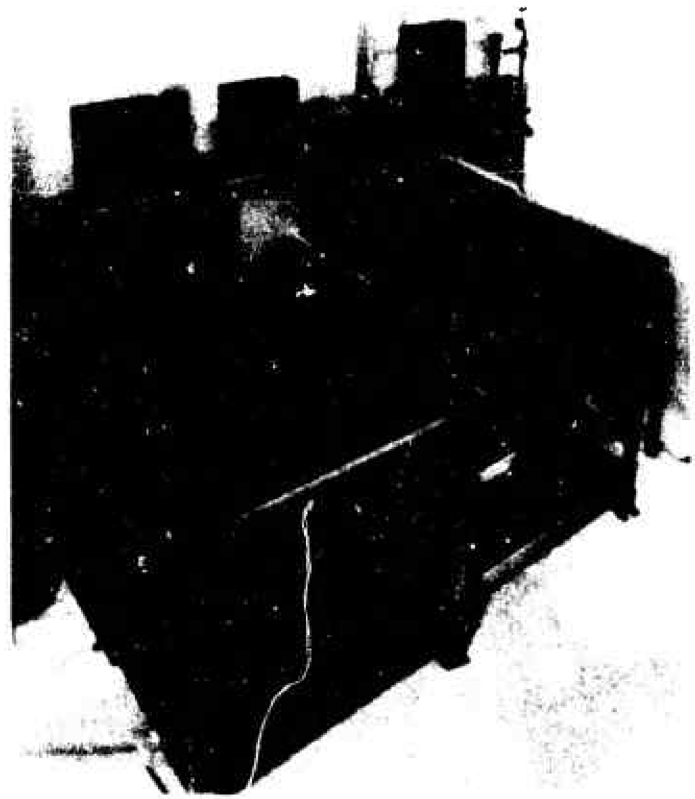

Fig. 56. Diapositive Plate Processor for 9½- by 9½-inch plates.

It is historically significant that work on the contact printer with exposure and doging control led to the development of the all-electronic system of exposure and dodging control known as the Log E equipment. Under the contract for the point light source printer, the contractor Reed Research, Inc., Washington, D.C., first demonstrated the electronic dodging concept to ERDL personnel and submitted a report recommending its development under the contract. Both the point light source printer (Fig. 57) and the all-electronic contact printer (Fig. 58) were constructed by

92. "Engineering Test of Diapositive Processing Unit," ERDL Report 1628-TR, May 1960.

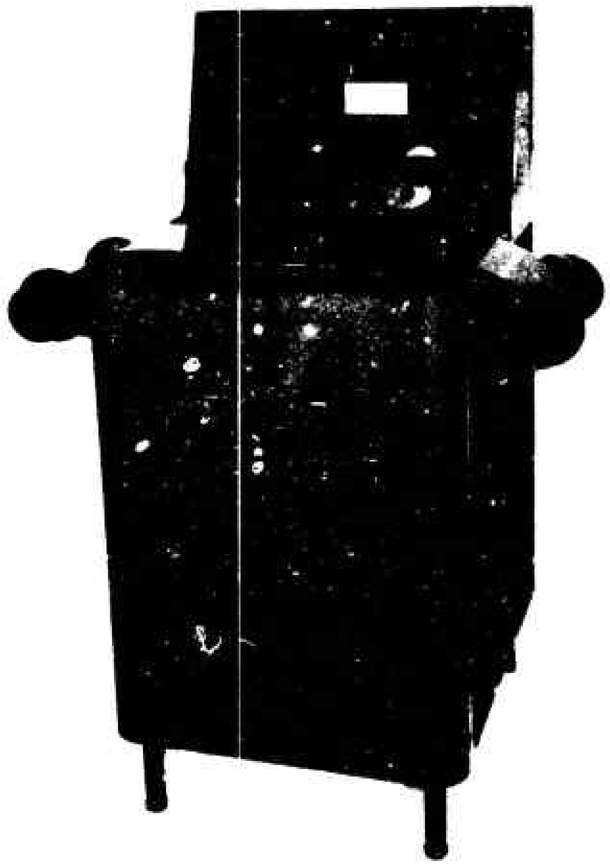

Fig. 57. Point Light Source Diapositive Plate Printer with exposure and dodging control.

Fig. 58. An early model all-electronic exposure and dodging control contact printer (Log E) produced by LogEtronics, Inc., based on principles developed under ERDL contract with Reed Research, Inc.

Reed Research, Inc. for engineer tests.[93] Following this, the electronic printers were developed commercially, and a commercial model 9-inch by 18-inch printer was procured and tested.

(e) **Field Artillery Plotting Equipment.** In 1946, a project was approved for the development of range and deflection protractors, coordinate scales, and gridded plotting sheets for the field artillery to provide equipment with better accuracy than items then available in consonance with the demands of improved weapons with good firing accuracy. This program resulted in the development of a family of aluminum range deflection protractors (Fig. 59), aluminum coordinate scale, and paper-aluminum foil laminate plotting sheets which were standardized in 1952. Following this, the Quartermaster Corps developed canvas carrying cases for the fire direction center equipment sets; and, in 1955, equipment specifications were revised to call for graduation in meters instead of yards at the request of the Continental Army Command. A final report[94] on the project was published in 1955, and the project was officially closed in 1956.

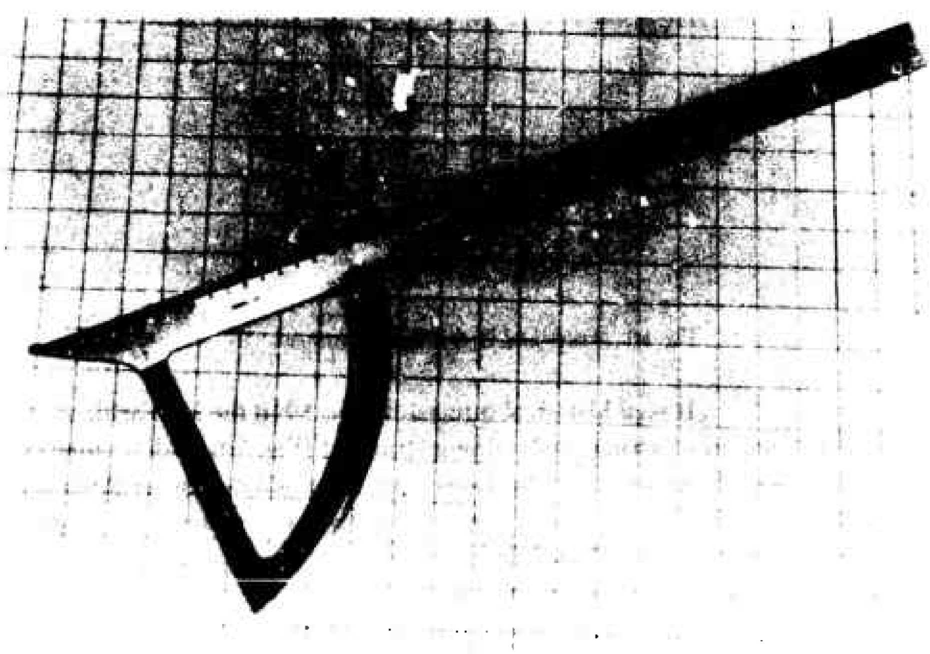

Fig. 59. Aluminum range and deflection protractor developed for field artillery in early 1950's.

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93. "Engineering Tests and Evaluation of Printers for the Preparation of 9½ x 9½ Inch Diapositives for the Precision Plotter," ERDL Report 1538-TR, 28 July 1958.

94. "Field Artillery Plotting Equipment," ERDL Report 1421, Final Report on Project 8-35-02-001.

Fig. 60. Range and Deflection Instrument.

It is of historical interest that in 1948 the field artillery requested the development of a range-deflection instrument (Fig. 60) to determine graphically and simultaneously ranges and deflections from any combination of three battery positions to a target to implement a newly developed observer fire-direction center procedure. Such equipment was developed under contract by the Union Instrument Company, Plainfield, New Jersey, and service test models were produced by September 1950. The U. S. Marine Corps, as a result of service tests in early 1951, indicated that with certain modifications the instrument was satisfactory for the intended use. The Army Field Forces, who had requested the development, concluded that the instrument was unnecessary since other types of data computers showed promise of being superior to the range-deflection instrument. The development was therefore suspended in July 1951.

c. **Cartographic Drafting Accomplishment – World War II to 1960.** Although responsibility for research in the field of materials for cartographic drafting was

assigned to the Department of the Army in January 1950[95] and, subsequently, by the Department of the Army to the Chief of Engineers in the same month,[96] it was not until 7 September 1951 that a formal project on cartographic drafting methods and equipment was approved by GSUSA. In the meantime, there had been some activity in this field under other approved projects, most notably the work on stable cartographic bases and some work on plastic scribing. Significant progress was made in both of these areas in the 1950's but the drafting phase still remained a critical factor in the late 1950's, limiting the speed of map production. Serious efforts then began to automate the cartographic process.

(1) **Stable Cartographic Bases.** The development of both translucent and opaque dimensionally stable cartographic bases was started in 1948 to provide material to overcome the deficiencies of paper bases, subject to intolerable dimensional changes, and plastic bases which would distort in high-temperature storage and had unsatisfactory drafting surfaces.

After initial investigation of commercially available bases,[97] a series of development contracts was awarded to discover better bases than those available commercially. The Keuffel and Esser Company worked on the improvement of glass cloth, but the project failed to meet dimensional stability requirements. The U.S. Rubber Company was unsuccessfol in producing a suitable paper-glass cloth laminate. Laboratory samples of translucent materials with exceptional dimensional stability characteristics were produced by Bjorksten Laboratories using plastic materials, glass fibers, finishes, and resins. However, the effort was unsuccessful in developing manufacturing procedures for commercial production. A research study by Reynolds Metals Company did develop paper aluminum foil laminates sufficiently improved to meet all military characteristics except the dimensional stability requirement.[98] In service test, however, the Army Map Service, the Air Force, and the Navy Hydrographic office all reported difficulty in using the material for their purposes. On the other hand, CONARC concluded that the paper aluminum foil laminate was suitable for Field Army use and recommended that it be adopted as standard in lieu of Bristol Board. A final report[99] on opaque bases was prepared in 1956 indicating the superiority of paper aluminum foil laminate over any other materials investigated.

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[95] RDB Memo 244/2, subject: Assignment of Responsibility to the Department of the Army for Research in the Field of Materials for Cartographic Drafting and Reproduction, 3 January 1950.

[96] Memo from GSUSA for Chief of Engineers, subject: Assignment of Research and Development Cognizance in the Field of Materials for Cartographic Drafting and Reproduction File CSGLD/F1-4891, 3 January 1950.

[97] "Test of Cartographic Bases," ERDL Report 1182, Interim Report, 4 October 1950.

[98] "Engineering Test of Opaque Cartographic Bases," ERDL Report 1190, 30 April 1953.

[99] "Dimensionally Stable Opaque Cartographic Bases," ERDL Report 1469-TR, 2 November 1956.

In the meantime, investigations continued on commercial and experimental translucent materials including polystyrene, polyfluorethene, other synthetics in sheet form, and also synthetic fiber papers and glass-reinforced plastics. These investigations resulted in the finding that coated and mechanically grained polyethylene terephthalate polyester sheeting ("Mylar") was sufficiently stable and offered a satisfactory drafting surface.[100] After service testing which generally indicated the superiority of this material over vinylite sheeting, which had been in use as an interim item, a final report[101] on this development was prepared. The report recommended that Mylar with a drafting surface replace the vinyl acetate supplied as a base in five engineer sets and that the project be closed almost 10 years after its inception in 1948.

(2) **Plastic Scribing.** When the cartographic drafting methods and equipment project began in 1951, a survey was made of cartographic drafting methods and equipment employed by other governmental and civilian organizations to form a base from which to chart the development program. As a result of this survey,[102] it was concluded that the project should be directed toward mechanizing grid layout and point plotting; improving compilation methods, color separation drafting, map symbolization, and design; the development of tools and procedures suitable for the plastic scribing process to be adopted by field mapping units; and continued study and development in the field of plastic scribing to provide methods for proceeding directly from scribed manuscript to the press plate. Between 1952 and 1957, plastic scribing was one of the major development activities of ERDL.[103] [104] This work resulted in the development of a set of tools for plastic scribing – Drafting Equipment Set No. 13 Plastic Scribing – with novel scribing instruments employing a spring-loading principle to control point pressure, permanent type scribing points, symbol template, measuring magnifier, and a correction pencil (Fig. 61). Considerable progress was also made in the development of dye-coated plastic sheeting. Later in 1958 and 1959, investigations of photomechanical methods of etching dye-coated and opaque scribing materials resulted in the development of suitable resist coatings and etchants. New techniques for applying blueline coating by a simple hand rub-on method was developed by ERDL, thus obviating the need for presensitized scribe material.

One unsuccessful effort was the development of a scribing instrument employing ultrasonics to produce dashed and dotted lines, clear large open areas

100"Engineering Test of Translucent Cartographic Bases," ERDL Report 1461-TR, 17 September 1956.

101"Final Report on Stable Cartographic Bases," ERDL Report 1542-TR, 3 September 1958.

102"Cartographic Drafting Methods and Equipment," ERDL Report 1305, First Interim Report, 7 July 1953.

103"Cartographic Drafting Methods and Equipment (Plastic Scribing Process)," ERDL Report 1339, Second Interim Report, 12 January 1954.

104"Plastic Scribing Color Separation," ERDL Report 1485-TR, 13 June 1957.

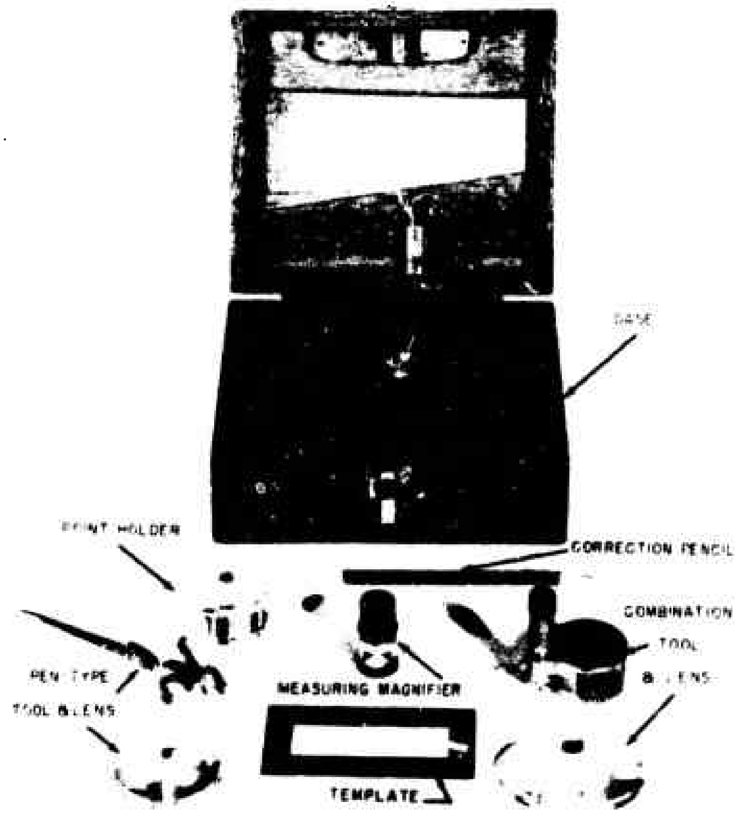

Fig. 61. Drafting Equipment Set No. 13 – Plastic Scribing.

on the scribe sheet, and scribe symbols such as railroad and depression contour ticks (Fig. 62). However, the work did demonstrate that the basic principles of ultrasonics may be applicable in the development of completely automatic equipment.[105]

(3) **Grid Ruling and Point Plotting.** Initial efforts in the early 1950's to provide better means for grid ruling and point plotting resulted in the development of a grid-ruling machine based on the isosceles sliding block principle. This had been suggested by Reed Research, Inc., as a result of their contracted research in this area. This item, developed under contract with the Union Instrument Company, had limited application during service tests and further development was discontinued.[106] Further work on grid ruling during the 1950's was limited to the investigation and test of commercially

[105] "Test and Evaluation of Ultrasonic Scribing Equipment," ERDL Report 1641-TR, June 1960.

[106] "Engineering Tests of the Cartographic Grid Ruler," ERDL Report 1486-TR, 17 June 1957.

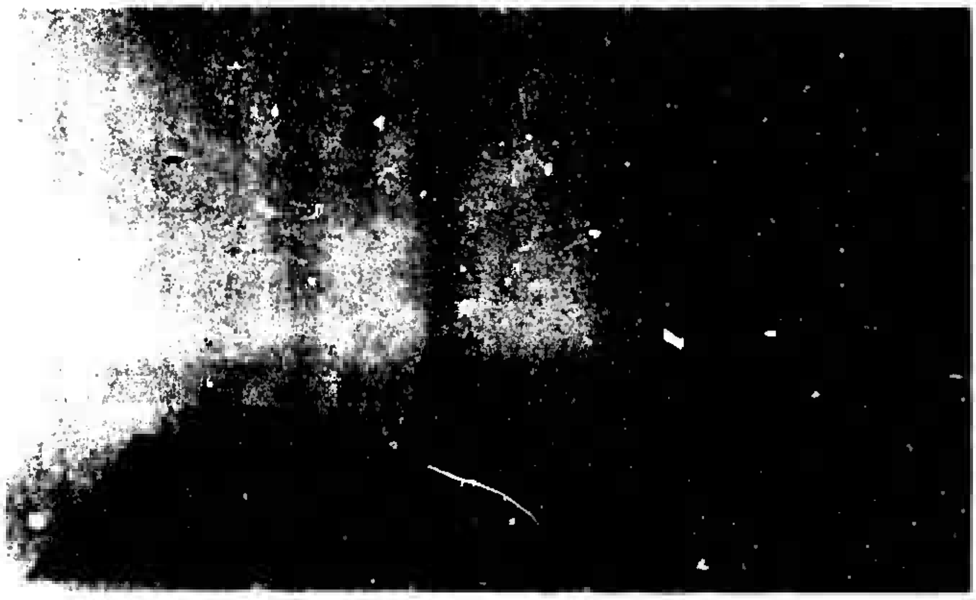

Fig. 62. The Ultrasonic Scriber – control panel, transducer, and commutators in holder.

available coordinatographs[107] to provide portable models suitable for field use and larger models for base-plant use.

(4) **Automation of Cartographic Operations.** The first organized effort to automate cartographic operations came in 1958 when a contract was awarded to the Benson-Lerner Corporation, Los Angeles, California, to conduct studies to improve or automate cartographic operations. As a result of this study, recommendations were made to develop automatic instruments for point plotting and grid ruling for scribing and for map lettering. It was also recommended that automatic line-following equipment for use in cartographic drafting be developed. Following this study, the requirements for a completely automatic, high-precision, point plotter and grid ruling device were developed by ERDL, and contract negotiations were initiated in 1959 to develop such an instrument.

d. Map Reproduction Accomplishments – World War II to 1960.

(1) **Research for Map Reproduction.** Research for map reproduction in the period from World War II to the establishment of GIMRADA in 1960 primarily concerned the development and simplification of lithographic equipment and techniques for map reproduction in the field. The need for greater efficiency was revealed in many situations in World War II where field conditions introduced problems not normally encountered in commercial practice. A need also developed to improve the quality of

107. "Tests and Evaluation of Precision Coordinatographs," GIMRADA Report 1-TR, July 1961.

lithographic reproduction of photomaps and mosaics so that they would more nearly equal full-tone photographic reproductions. One of the earliest accomplishments in this area was the first presensitized lithographic plate produced in the United States. This development was actually a byproduct of work on the ammonia process for the reproduction of photographs, when a plate coated with a diazo type compound was produced which merely required exposure and gumming thus eliminating the inking, developing, and etching steps of the conventional albumin lithographic plates. Engineer Board tests early in 1949 showed that reproductions obtained from diazo-sensitized acetate plates were superior to reproductions from conventional grained metal plates. Following this, the development of presensitized lithographic plates was pursued by a number of lithographic suppliers; and, in 1952 and 1953, the Lithographic Technical Foundation, under contract with ERDL, evaluated a number of these plates procured on the commercial market. The information developed in these evaluations was used to prepare a specification for presensitized plate procurement: Specification MIL-P-13692(CE), "Plates Lithographic, Printing, Presensitized, with Processing Chemicals," and a Technical Bulletin TB Eng 159, "Presensitized Lithographic Plates."

During 1951 to 1952, an air ductor dampening system designed to replace the conventional molletin roller dampening system on the lithographic offset press was tested by ERDL. The tests showed that the system would work satisfactorily but that a simplified method to apply moisture to the lithographic plate had not been achieved. Therefore, the process was not adopted. Paper dampener covers were also investigated, and a testing program carried out with the cooperation of the Map Reproduction Branch of the Engineer School revealed that excellent results could be obtained by skilled operators. However, roller settings were too critical for trainees and, therefore, the process could not be recommended for field applications.

In an effort to provide better quality lithographic reproduction of continuous-tone imagery, the investigation of an unscreened, simulated, continuous-tone process called "collotype" was initiated in 1952 by contract with Triton Press, Inc. The objectives here were similar to those of the Bloom process developed by Sergeant Bloom before World War II. Under this contract, controls were established, procedures and techniques were adapted to the lithographic offset press, and inks and humectants and their effects on the lithographic process were investigated. Further development and test of the process by ERDL brought it to the point where an experienced platemaker could produce satisfactory plates. However, a comparison of results obtained with a photograph and a conventional 300-line offset lithographic reproduction[108] showed no great improvement in the amount of detail in the reproduction as compared to the 300-line screen. The photograph was far superior to the other method of reproduction in

108 "Evaluation of Offset Collotype Printing for the Field Reproduction of Aerial Photographs," ERDL Report 1465-TR, 5 October 1956.

terms of quality. Here, again, as with the dampening systems investigated, the process was found to be too critical for field application.

Lithographic plates, platemaking materials, and platemaking techniques were major areas of investigation in the mid-1950's. The Lithographic Technical Foundation was contracted in 1952 to evaluate both standard and experimental lithographic platemaking techniques and materials. This work continued into 1954, and resulted in a recommendation for a considerable rewrite of the Army Technical Manual on Map Reproduction, TM 5-245, to bring the manual up to date. Under contract to the Harris-Seybold Company in 1955 to 1956, three casein plate coating formulations which met most of the requirements were produced. However, the best development was the discovery of a synthetic colloid (PVM/MA), the copolymer of methyl vinyl ether and maleic anhydride, which showed excellent promise both as a plate coating and as a plate desensitizer. Evaluation by the Lithographic Technical Foundation and ERDL demonstrated, however, that the synthetic material was somewhat slower in exposure time and did not produce as tough an image as the conventional colloids used in lithographic platemaking. These deficiencies were largely overcome by a blend of PVM/MA and casein developed by the Army Map Service.

The most significant accomplishments of ERDL in lithographic platemaking in the mid-1950's were the development of techniques for using aluminum plates instead of zinc, the development of the brush plate surfacing method, and the development of wipe-on techniques for applying plate coatings to the base plate (Fig. 63).

Fig. 63. Experimental brush plate surfacing equipment, 1955.

The brush plate surfacing technique[109] allowed elimination of the large, heavy marble plate graining machine from the map reproduction train, and the wipe-on technique permitted elimination of the plate whirler.[110]

Improvement of military map paper was investigated from 1953 to 1957. An earlier attempt had been made by the S. D. Warren Company to produce durable, lightweight map paper with a pigmented printing surface and wet-strength properties. The work in the 1953 to 1957 period, done largely by the National Bureau of Standards, included a study of the reaction of the paper fibers and the resin used to give paper its wet strength; investigation of paper-plastic laminates; the use of synthetic fibers such as Nylon, Dacron, and Orlon; and the use of combinations of synthetic and natural fibers. Some evaluation of experimental papers, manufactured by commercial organizations was performed to determine suitability for map printing. None of the papers developed and tested showed sufficient improvement or reduction in manufacturing costs to warrant changes in specifications for map paper.

The investigation of the so-called "dry offset" printing process in 1956 and 1957, by which the press dampening system would be eliminated, was also noteworthy. As practiced commercially, the lithographic plate was prepared by photoengraving techniques (the nonimage areas being etched to a depth of 0.010 to 0.012 inch). ERDL rendered the nonimage areas of the lithographic plate ink-repellent by a surface treatment or by the use of additives in the press ink. Although varying degrees of success were achieved with the process, it was not considered adaptable to field Army use.

In the late 1950's, research work on lithographic reproduction was de-emphasized, and the program on research for map reproduction was oriented toward the more fundamental question of the proper output media for effective communication of topographic and related data to the military user. In 1959, a purchase description was written and negotiations were initiated for a contract study designed to determine the types of topographic and related data that would be required by the Army in the time period 1965 and 1975 and to formulate a family of output media for their effective communication. It is of historical interest to note that this negotiation resulted in a contract with Aeronutronics, a division of the Ford Motor Company, and an effort was made to establish the basic requirements of the foot soldier for topographic data. While the objectives were limited and the approach taken and the results achieved were questionable, the effort was so maligned that the program was not continued. However, the Ad Hoc Committee of the Army Scientific Advisory Panel found in its investigation of ETL in 1967 that this type of program was badly needed. Therefore, GIANT-75 and GIANT-85 studies were implemented by the Combat Developments Command in 1968.

109. "Brush Surfaced Lithographic Press Plates," ERDL Report 1452-TR, 28 June 1956.

110. "Evaluation and Test of a Modified Plate Process Section, A Proposed New Photomechanical Process Section and a Redesigned Brush-Surfacing Machine," ERDL Report 1560-TR, 6 January 1959.

(2) **Rapid Production of Photographic Prints for Ground Forces.** In the immediate post World War II period, both the Williamson and the Garraway rapid photographic printers were being tested by the Army Field Forces for the quantity reproduction of photographs and photomaps in the field for the Army. The Garraway printer was developed by the Engineer Board, and the Williamson printer had been developed in England during World War II. These tests were completed in 1950. Neither machine was considered satisfactory, and it was recommended that the new ammonia process and equipment be developed for this application. Ammonia process equipment had been under development by ERDL since 1947 when a development project was initiated. The primary objective was to reproduce line tracings and drawings. and a secondary objective was to reproduce limited quantities of aerial photographs and mosaics in continuous tone.[111] By 1950, a 42-inch printer-developer had been developed.[112] In 1950, the project was revised to place the primary emphasis on reproduction of continuous-tone photomaps and aerial contact prints from cut or roll film up to 22 inches in width and to develop or perfect the process to improve diazo type materials. Under the revised project, various commercial ammonia process printer-developers were investigated including 24-inch machines manufactured by the Ozalid Corporation and the Paragon-Revolute Corporation[113] and the "Ozomatic" manufactured by the Ozalid Corporation in 16-inch and 30-inch size (Fig. 64). Considerable work was done on the development of improved diazo papers under contract with the Keuffel and Esser Corporation, resulting in plastic coated papers of good color and color constancy. Work at ERDL concentrated on the production of the ammonia process intermediate[114] required for the process since it is a positive working one, that is, a positive is produced through contact exposure with a positive.

By 1956, the development was highly advanced. The process did not require the liquid chemicals and large quantities of water required for the photographic process; development was achieved simply by exposure to ammonia vapors. This was a distinct advantage. The disadvantage was the need for an intermediate transparency, and there was some objection to the color of the image – it was not a solid black on white.

This development was suspended in 1956, and the Continental Army Command indicated that no further work on aerial photo reproduction was

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[111] "Light Sensitive Diazotype Paper for Tropical Use," ERDL Report 1109, 8 April 1949.
"Sensitizers for the Production, by the Diazo-Ammonia Process of Non-Photographic Blue Line Drafting [illegible]ds," ERDL Report 1122, 6 May 1949.

[112] "Engineering Tests of Experimental Ammonia Process Printer-Developer," ERDL Report 1174, 6 July 1950.

[113] "Engineering Tests of Two Printer-Developer, Ammonia Process, 24-Inch," ERDL Report 1292, 12 May 1953.

[114] "Preparation of Intermediates for the Quantity Reproduction of Aerial Contact Prints by the Ammonia Process," ERDL Report 1253, 12 September 1952.

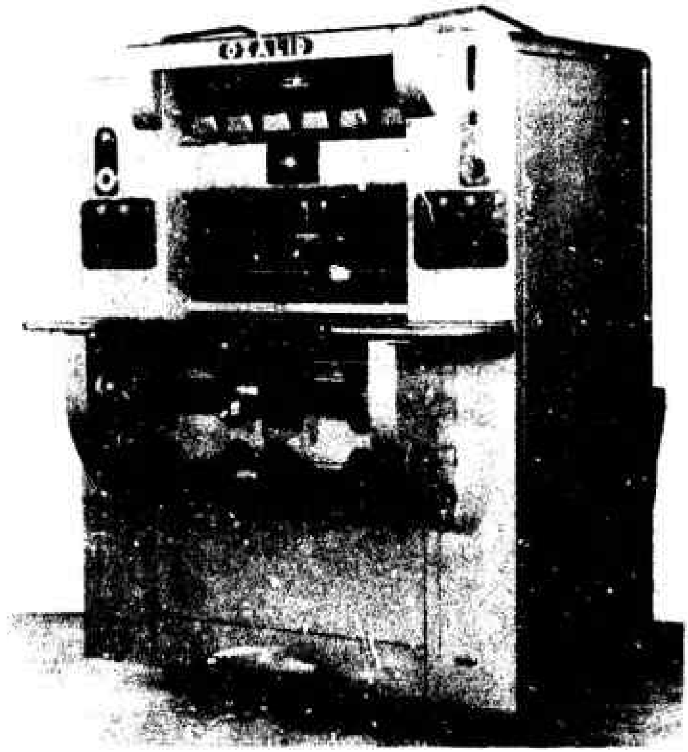

Fig. 64. Ammonia process machine developed for quantity production of continuous tone photography by the Diazo process.

required by the Corps of Engineers since the responsibility for quantity aerial photo reproduction had been assigned to the Signal Corps.

In the meantime, in the period from 1952 to 1956, ERDL developed a motorized Aerial Photo Reproduction Equipment Train to provide a better facility for the Aerial Photo Reproduction Company. The assemblage included five expansible van sections on semitrailers and was designed to produce 25,000 10-inch by 20-inch prints per 8-hour operational period. The unit was accepted by the 67th Engineer Aerial Photo Reproduction Company for service test in November 1953. However, the project was cancelled in January 1956 before the service test report was published when responsibility for quantity reproduction was assigned to the Signal Corps.

(3) **Mobile Copy Camera.** One of the first projects to be implemented at the close of World War II was the development of a completely new darkroom-type 24-inch by 30-inch process copying camera suitable for the reproduction of military maps and charts by field organizations of the Army and Air Force (Fig. 65). Experience

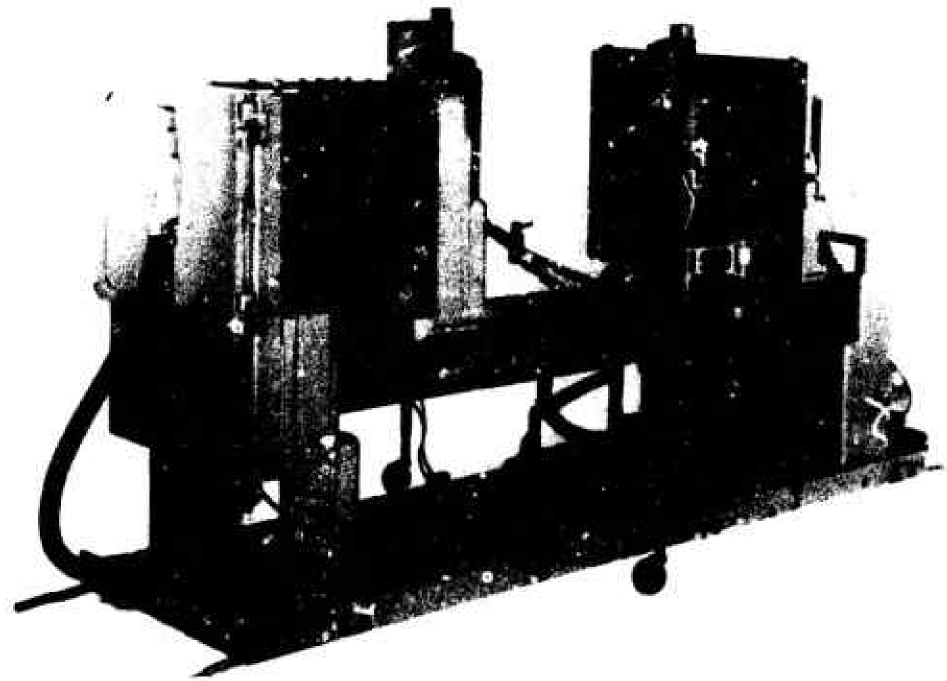

Fig. 65. The 24- by 30-inch mobile process camera.

during the war had proved the necessity for items specially designed for military application to obtain the required simple rugged, compact and lightweight features.

The engineering test model camera was developed by the Zarkin Machine Company and was delivered to ERDL in July 1948.[115] A service test model was procured in 1950, and service tests were conducted by the Engineer Test Unit at Fort Belvoir, Virginia, between 20 February and 7 August 1951.[116] The item was eventually standardized and the project was closed in February 1954 after additional testing had been conducted in 1952 and 1953 dealing with tropicalization of the camera and safe storage during extremes of temperature.

(4) **Lithographic Offset Presses.** Between World War II and 1960, there was a series of lithographic offset press development projects. The first of these implemented in July 1945 was the development of a rotary offset lithographic press specially designed with lightweight frame and low center of gravity for air transport and mounting in mobile mapping vans (Fig. 66). This development pursued a normal course without

115. "Development and Testing of Camera, Copying, Mobile, Process, 24- by 30-Inch," ERDL Report 1194, Interim Report, 6 April 1951.

116. "Development of 24- by 30-Inch Mobile Process Copying Camera," ERDL Report 1229-L, 6 May 1952.

major difficulty or delay. The engineering test model was developed by Webendorfer Division, American Type Founders, Inc., in 1949.[117] A service test model was procured and delivered to the Engineer Test Unit, Fort Belvoir, Virginia, in 1951. Testing was completed in August 1951. In the meantime, the U. S. Air Force proposed a change in sheet size requirement from 22 inches by 29 inches to 22½ inches by 30 inches. This was accomplished simply by a change in procurement specifications. The item[118] was classified standard in February 1952 and the project was officially closed by Corps of Engineer Technical Committee action later that year.

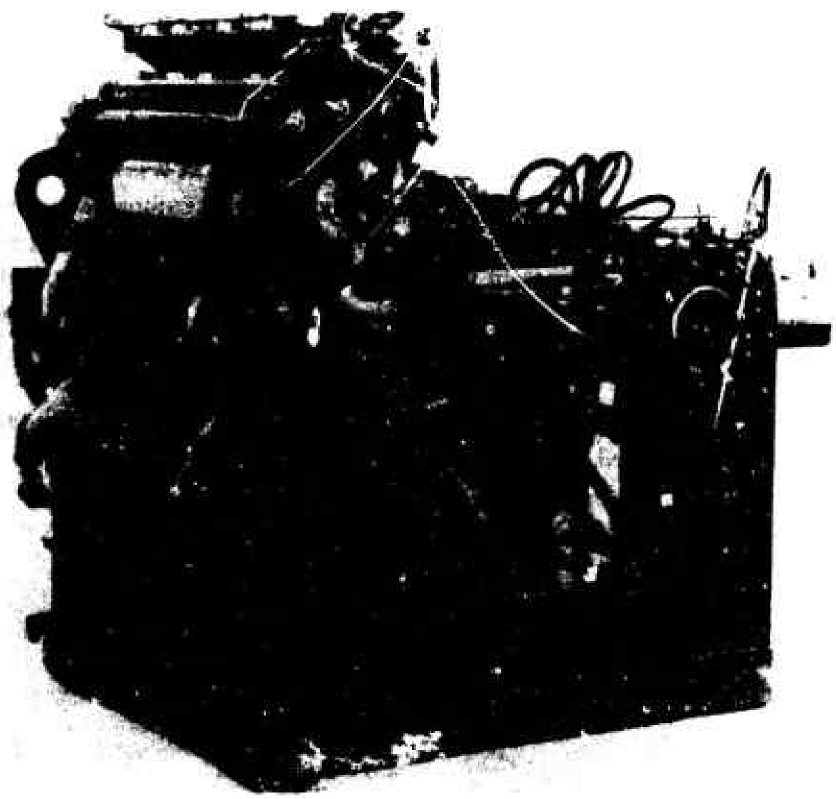

Fig. 66. Lightweight lithographic offset press – 22.5 by 30 inch.

In March 1952, development of a web-fed (roll-fed) lithographic offset press began. The objective was to provide equipment for high-speed map printing in emergency situations to complement sheet-fed presses. A contract was awarded to the Michle Printing Press and Manufacturing Company in 1952 for a design study. This

117. "Development of Lithographic Offset Press, 22- by 29-Inch Sheet Size," ERDL Report 1172, Interim Report, 16 June 1950.

118. "Development of Lithographic Offset Press, Mobile, 22.5 by 30-Inch Maximum Sheet Size," ERDL Report 1247, Final Report, 1 August 1952.

study was completed in October 1953, and it was concluded that a multiunit, web-fed press which prints after sheeting was best suited to the requirement. After evaluating the Miehle report, however, it was concluded that the requirements for such a press and the potential savings offered were not sufficient to warrant development at the time. The project was cancelled in November 1955.

In February 1957, a project was initiated to develop a lightweight, two-color offset press to increase the efficiency of the field map reproduction units. On solicitation of proposals from industry, only two proposals were received – one only for a feasibility study, and the other for the design and fabrication of a press in Europe. The development was then dropped from further consideration because of lack of funds.

(5) **Spirit Duplicator.** As a result of the unsatisfactory performance of the gelatin duplicator in tropical climates in World War II, a project was approved by the Army Service Forces in November 1945 to develop a lightweight, compact, dependable duplicator in the 22-inch by 29-inch size which would operate satisfactorily under all field conditions. This type of equipment was required in the field for rapid reproduction of overlays, map overprints, etc., required in such small quantities and on such short notice that lithographic reproduction was impracticable or unjustified.

To meet this requirement, ERDL developed a rotary, sheet-fed, hand-operated duplicator based on the spirit process of duplication (Fig. 67).

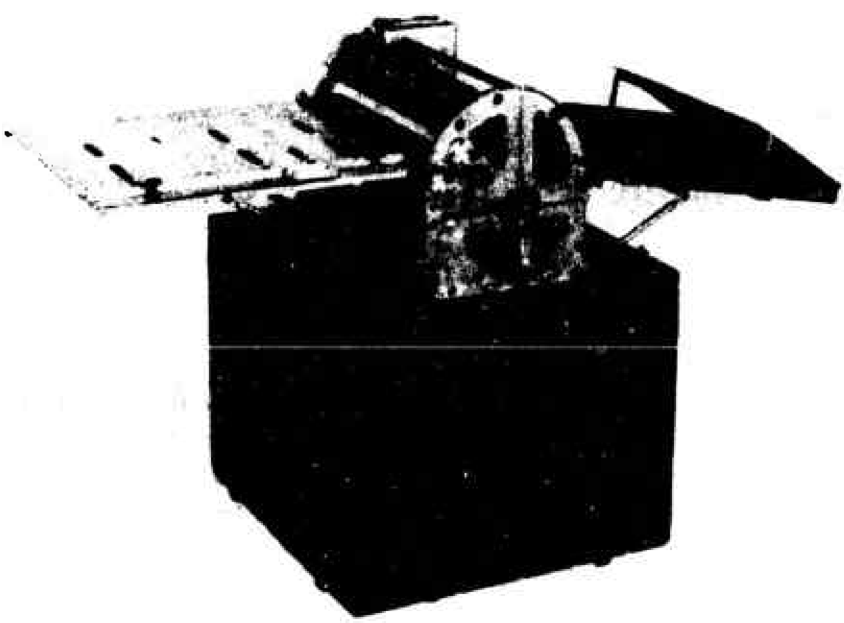

Fig. 67. Spirit Duplicator.

An experimental model spirit duplicator was procured from the Rex-O-Graph Company and was service tested by Army Field Forces Board No. 2 in 1947 to 1948. As a result of these tests, the spirit duplicator was redesigned by ERDL, engineering drawings were prepared, and a revised duplicator was fabricated in the ERDL shops. This was one of the rare cases where the final test model was produced in this fashion.

The development of the spirit duplicator and all testing including tests in temperature extremes and the final report on the development were published in 1952.[119]

(6) **Lightweight Paper Cutter.** Another of the early post-World War II projects was the development of a lightweight, compact, hand- and power-operated paper cutter capable of trimming 22-inch by 29-inch map paper on both dimensions. The cutter was required to replace a 23-inch, hand-operated paper cutter that was inadequate because of changes in standard field press and map size. This project was approved on 8 November 1946 by the War Department General Staff.

An engineering test model was constructed by the Zarkin Machine Company, New York City, and was delivered to ERDL in June 1949. This was a bench model portable unit that measured 41 inches by 41 inches by 25 inches and weighed approximately 100 pounds.

After testing, the Zarkin Machine Company was contracted to construct a service test model, but the contractor experienced considerable difficulty in consummation of the contract. It was eventually cancelled by mutual agreement and at no cost to the government in 1951.

In the meantime, it was found that the Harris-Seybold Company manufactured for the commercial market a 26½-inch paper cutter which very nearly met the military requirements. A contract was negotiated with Harris-Seybold for a 30½-inch cutter embodying the principles of their 26½-inch cutter but also fulfilling all military requirements. This cutter was delivered to ERDL in July 1952 (Fig. 68). After service test by the Engineer Test Unit at Fort Belvoir, Virginia, in 1953 and some further modification to overcome deficiencies noted in these tests (specifically, the replacement of the cast aluminum alloy knife assembly by a steel assembly), the item was classified standard in November 1954 and the project was closed.

(7) **Light Sources for Photolithography.** The project for the development of an improved light source for photolithographic processes, which was initiated

119 "Development of 22- by 29-Inch Spirit Duplicator," ERDL Report 1227, 28 April 1952.

Fig. 68. Lightweight paper cutter.

in October 1946, turned out to be an abortive attempt to replace the arc lamps which were considered unsatisfactory because of the excessive heat, smoke, and noxious fumes, high power consumption, and nonuniform illumination. After almost 9 years of effort, it was finally concluded that the carbon arc lamp was still the best means of illuminating the copy board of a copy camera. The investigation did determine that the motor-driven carbon arc lamp was superior to the solenoid-operated lamps, and military specifications were revised accordingly. The project was cancelled in April 1955.

The initial approach in this project was to develop an electrical discharge light source, and an experimental model was designed and produced under contract by the American Speedlight Corporation. This light source was found unsatisfactory primarily because of complex electronic circuits requiring frequent servicing, the excessive bulk and weight of the unit, length of required exposure, and the need for an auxiliary light source for focusing and centering copy in the film plane.[120]

(8) Photolettering Machines. Photolettering machines were investigated starting in February 1947 and continuing through the 1950's and beyond. The objective

[120] "Electronic Flash Light Source for a Process Copying Camera," ERDL Report 1246, 28 July 1952.

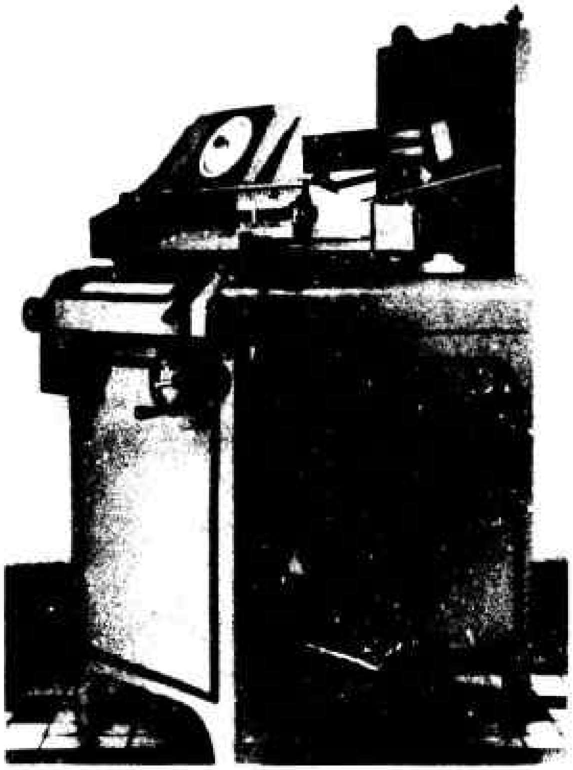

Fig. 69. The Hadego photo compositor.

was to provide a suitable machine to replace the letter press equipment used in World War II to produce marginal data, titles, place names, etc.

Numerous commercial lettering machines were tested under the project, including a modified commercial Fotosetter Photolettering machine,[121] the Fairchild Lithotype,[122] a desk model Fotosetter,[123] an ATF-Hadego Photo Compositor (Fig. 69),[124] the Coxhead Liner, the Typro Composer,[125] and the Photonymograph[126] manufactured in England (Fig. 70). None of these proved to be satisfactory, but the operational tests of the Photonymograph in 1958 indicated that this machine met the

121 "Fotosetter (FS-4) Photolettering Machine," ERDL Report 1259, 28 October 1952.

122 "Fairchild Lithotype Composing Machine," ERDL Report 1241, 7 July 1952.

123 "Desk Model Fotosetter Photo-Lettering Machine," ERDL Report 1329, 6 November 1953.

124 "ATF-Hadego Photocompositor Photolettering Machine," ERDL Report 1414, 22 July 1955.

125 "Typro Composer Photolettering Machine," ERDL Report 1504-TR, 16 October 1957.

126 "Test and Investigation of the Photonymograph (PN-4)," ERDL Report 1537-TR, 24 July 1958.

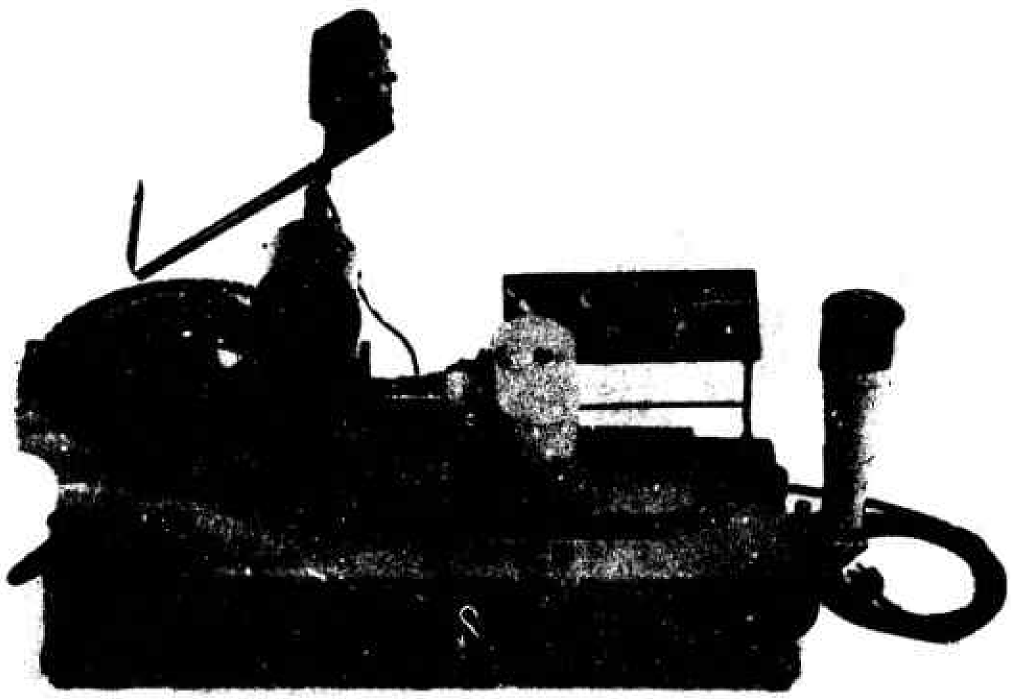

Fig. 70. The Photonymograph.

military characteristics more closely than any tested up to that time. Minor deficiencies were noted, and three instruments incorporating the recommended changes were requested from the British for user tests.

In the meantime, an instrument called the Headliner (Fig. 71), manufactured by the Varitype Corporation, became available in this country. This was an improved version of the Coxhead Liner which had been investigated earlier. Tests of this machine indicated that it was superior to the Photonymograph from the standpoint of economy and efficiency of operation.[127] Three of these instruments, with modification to meet military requirements, were procured in 1959 for user tests. One of the three Photonymographs was received from the British in 1959. Concurrent tests were conducted, and eventually the Headliner instrument was adopted.

(9) **Motorized Map Reproduction Sections.** In 1950, a project was initiated to modify and modernize the seven standard engineer mobile map reproduction sections, to adapt the van body dimensions to the new ordnance chassis, and to revise the interior layouts to accommodate new map reproduction equipment developed since World War II.

[127] "Test and Evaluation of the Headliner Model 400," ERDL Report 1568-TR, 29 April 1959.

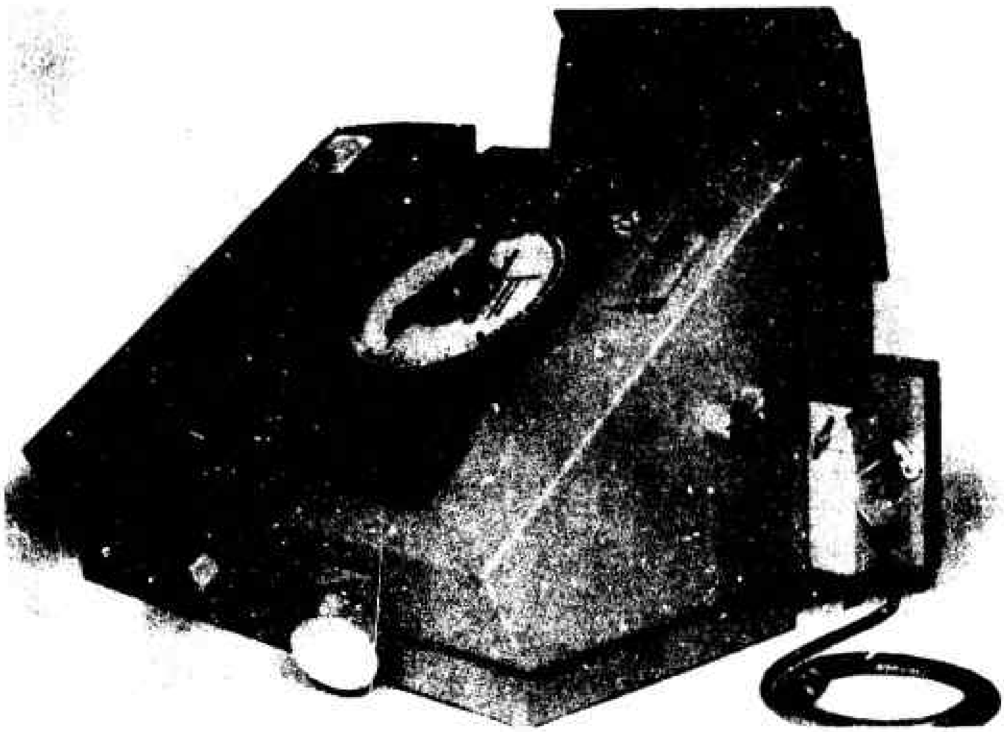

Fig. 71. The Headliner.

The first step was to develop a new van body with Army-wide standard heating and air conditioning equipment. The design included a new type of floor with radiant heating and a compartment interchangeable with the rear van body doors to extend the body 3 feet to provide darkroom space for the camera section.[128]

Development and all tests were completed in 1959.[129] The new section incorporated the newly developed brush plate surfacing equipment in lieu of the plate graining machine and a new photomechanical negative processing section[130] designed to provide better facilities for handling plastic scribing materials and color proving (Fig. 72).

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128 "Combination Map Reproduction Van Body," ERDL Report 1536-TR, 23 July 1958.

129 "Evaluation and Test of a Modified Plate Process Section, a Proposed New Photomechanical Process Section and a Redesigned Brush Surfacing Machine," ERDL Report 1560-TR, 6 January 1959.

130 "Engineering Tests of a Temperature Controlled Processing Unit, Deep Tank, for Photomechanical Film," ERDL Report 1599-TR, 1 October 1959.

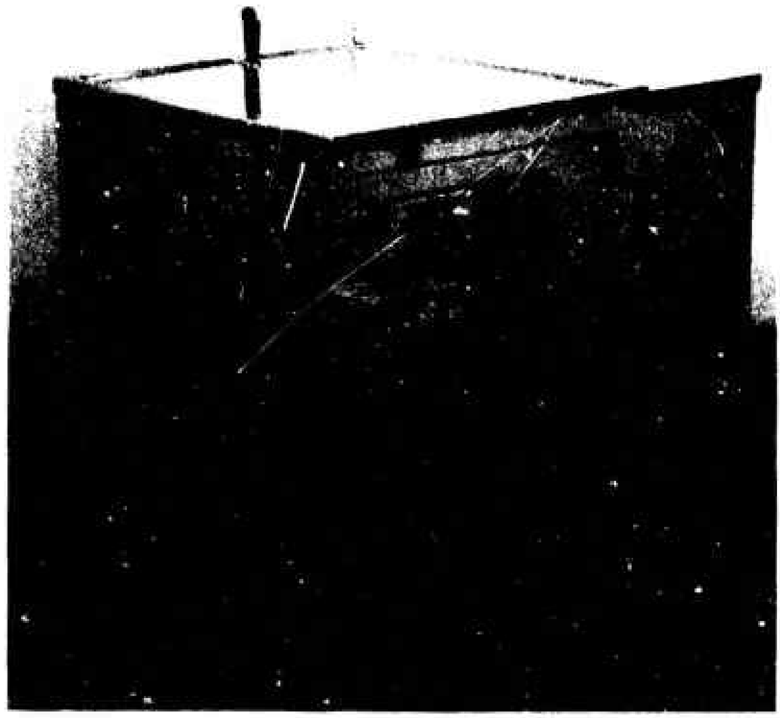

Fig. 72. Photomechanical film processing unit.

(10) Electrostatic Printing. The development of electrostatic printing by the Corps of Engineers actually began in 1952 when a project was approved by the General Staff, U. S. Army, to investigate and appraise current developments in xerography. In addition, the project was to determine the possibilities of the process for field production of lithographic plates and to evaluate the report on the long-range possibilities of a complete xerographic printing process for the reproduction of maps.

This investigation was pursued in the mid-1950's through a series of contracts with the Haloid Company (now the Xerox Corporation). The investigations under these contracts were performed by the Battelle Memorial Institute, Columbus, Ohio. The initial work included investigations of cascade and powder cloud development of electrostatic images on selenium xerographic plates and subsequent transfer by heat, pressure, and electrical discharge to a lithograph press plate. Later, a magnetic brush image development technique was developed, and still later a procedure was devised for reproducing 300-line halftones of good image quality on a zinc oxide-silicone plate coating using magnetic brush development. This work by Battelle for the Haloid Company under ERDL contract furnished much of the technology subsequently applied in the famous Xerox copying machines. As a part of this research, an experimental

Xerographic-Lithographic plate processing and transfer machine was produced and evaluated by ERDL in 1955.[131]

Further work at Battelle Memorial Institute resulted in development of the process to make nonimage areas of a zinc-oxide silicone coated plate water receptive and ink repellent. Thus, the plate could be used directly on the press as a lithographic printing plate.[132] This led to the development of the experimental electrostatic platemaking equipment in 1958 under contract with Photo-Devices Inc. (Fig. 73). The equipment was delivered to ERDL in November 1958. It did a creditable job of producing quality lithographic press plates but was somewhat inconsistent. Nevertheless, it was never adopted for field or other application because presensitized plates or brush surface plates with wipe-on coating were considered more suitable approaches.

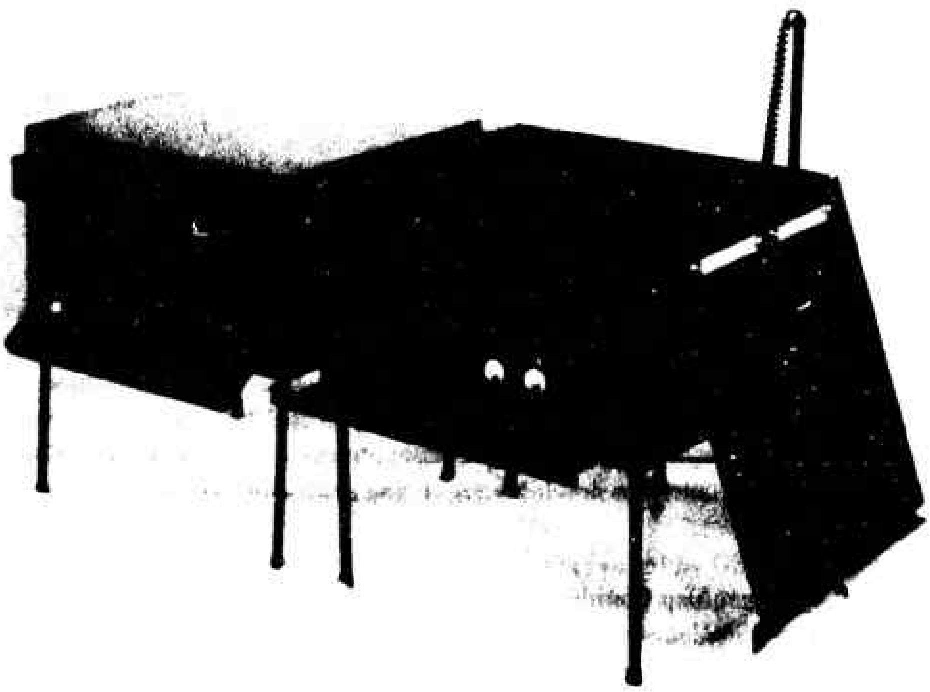

Fig. 73. Experimental electrostatic plate making equipment, 1958.

By the late 1950's, progress in the development of Xerography had reached the point where the process could be seriously considered for a complete printing

131"Evaluation of Experimental Xerographic Process for Lithographic Platemaking," ERDL Report 1417, 28 July 1955.

132"Evaluation of a Xerographic Process Preparing Zinc-Oxide-Silicone, Binder-Type Lithographic Plates," ERDL Report 1545-TR, 28 December 1958.

system to reproduce maps. In 1958, a contract was awarded to the Haloid Company to design an electrostatic printing machine. This contract, completed in July 1959, produced a design based on a "touchdown" development system. However, work continued after the close of the contract at the contractor's expense. In October 1959, a report was submitted by Haloid recommending a selenium transfer system using a selenium drum in conjunction with high-speed cascade developing, electrostatic transfer from drum to paper, and heat-image fusion.

In the meantime, the Defense Standards Laboratories, Woodville, South Australia, announced their work on the use of liquid-immersion development of electrostatic latent images which produced images of outstanding quality. Also, the Radio Corporation of America Laboratories, where work on this process had been underway for several years, submitted an unsolicited proposal to design and construct a demonstration model electrostatic printing machine using a 22½-inch web of zinc oxide-binder coated paper and liquid development. This machine would print from 70-mm microfilm separation positives and would, therefore, be ideally suited to the then emerging concept of field map reproduction. Under this concept, maps would be produced in the field on demand rather than by advanced reproduction, storage, and distribution of the large quantities of maps required in an Army operation.

A contract was awarded to RCA Laboratories in January 1959 for the demonstration model which was delivered in December 1959 (Fig. 74). In December 1959, contract negotiations were initiated with three commercial organizations for the design and construction of an experimental multicolor electrostatic printing machine. Therefore, by early 1960 the development of a multicolor electrostatic printing machine had been launched, but a decision concerning the basic process to be used in the system — selenium transfer or liquid-emersion development of zinc oxide-silicone coated paper — had not been made.

(11) **Target Map Coordinate Locator.** The concepts of military operation in the late 1950's employing long-range, surface-to-surface missiles led to the requirement for equipment and facilities to enable rapid access to map information and the determination of map coordinates of potential targets or for other military purposes throughout the areas commanded by these modern missile systems. As a potential solution to this problem, a project for the development of the Target Map Coordinate Locator was approved in March 1958 by GSUSA. A contract was awarded to the Fairchild Camera and Instrument Corporation in 1958 for the design and fabrication of the Locator and the essential equipment for the preparation of color micromaps. The design was approved in 1959 and fabrication was started (Fig. 75).

(12) **Color Separation.** ERDL work on electronic color separation began in the early 1950's. A contracted investigation by Edward Stern and Company in 1952

Fig. 74. Demonstration model electrostatic printing machine by RCA (1959).

and 1953, followed by further in-house work in 1954 and 1955,[133] concluded that a suitable scanning machine could be developed adopting design features from commercial experience but embodying new concepts for color recognition.

In July 1955, a project was approved by GSUSA to develop such a machine. This project was to provide a scanning device, based on electronic color recognition principles, which would be suitable for use in base or field topographic units to prepare color separation media from multicolored printed maps or map manuscripts such as captured maps or a single library copy map.

A development contract for this item was awarded to Outlook Engineering Company, Alexandria, Virginia, in January 1956. The design and fabrication of an experimental model was completed early in 1958.

133. "Evaluation of Color Recognition Devices for Making Color Separation From Multi Color Maps and Charts," ERDL Report 1401, 10 May 1955.

Fig. 75. Experimental model target map coordinate locator, Fairchild Camera and Instrument Corporation (1960).

The equipment produced was a flatbed scanning device with electronic color recognition which was rather successful in recognizing and printing major map colors, but the equipment had extensive mechanical and electronic deficiencies and the contract was finally terminated.

In the meantime, in-house tests were initiated using a modified process color separation technique which showed promise of meeting the basic requirement more simply and directly. This process used standard photographic filters to produce separations on stable base films to be printed by cyan, magenta, and yellow process color inks. In view of this, the development of the electronic scanning color separator equipment was terminated.

(13) **Terrain Model Making.** During World War II, the terrain model and the plastic relief map proved to be valuable and desirable methods of presenting terrain information for use in both operations and operational planning. While troop units were provided with equipment for the production of terrain models, they were poorly equipped since no standard set of model making equipment was available. Special shipments of improvised material, mostly nonstandard and not available from normal supply channels, were necessary. Further, the techniques of construction and reproduction then available did not adequately meet requirements for fast, initial construction and large output of duplicates in a short time.

Two programs were implemented in December 1947 to overcome these limitations. One program was the development of a mobile terrain model making equipment set. By 1951, the terrain model-making equipment, portable, set No. 1, general purpose,[134] had been engineer and service tested. Further action on the project to mount the equipment in motorized sections was held in abeyance pending a re-evaluation of the requirement, and work was finally terminated in 1958. The other program was designed to develop more efficient methods to produce terrain models in the field and in base facilities of the Army.

Under the terrain model production methods program in the late 1940's, investigations led to the adoption of a German pantograph machine and a collimating shadow projector for base plant application. Bakelite VU 5801 was selected as the material for relief maps for both base and field plant operations.

A little later a reliefograph machine was procured and tested and a developed surface cutter was designed at ERDL and tested.[135] Neither of these proved suitable; the reliefograph machine was not sufficiently accurate and the developed surface cutter required extensive redesign which was not warranted.

In 1959, a contract was awarded to the Bausch and Lomb Optical Company for basic research on an automatic topographic scanning device. This contract, completed in 1952, demonstrated the feasibility of automatically locating the consecutive position of terrain points in a high-contrast, three-dimensional model formed by a pair of overlapping aerial photographs oriented in multiplex projectors. A breadboard model, developed under this contract, transmitted the positions of these terrain points to a plastic cutter which produced profiles of the terrain. The original concept was that this approach would be applicable to the automatic production of terrain models. As it

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134 "Terrain Model Making Equipment, Portable, Set No. 1, General Purpose," ERDL Report 1192, 20 January 1951.

135 "Reliefograph Machine," ERDL Report 1189, 19 December 1950.

turned out, this was actually the beginning of the development of automatic mapping equipment.

In 1956, after investigation and rejection of a servomechanical model making instrument based on the profile lamination system in 1953 (Douglas Tool Company contract) and the design of a semiautomatic model making machine by Reed Research in 1955, a contract was awarded to the Kaiser Aircraft and Electronics Corporation for a prototype, semiautomatic, model-carving machine (Fig. 76). Fabrication of this machine was completed in 1958. It was designed to automatically sense contour lines as it scanned a contour transparency which was drum mounted immediately in front of an operator and thus control and drive a cutting tool which carved the profile in a block of wax. An operator was required to monitor the operation and to indicate to the device by pushbutton control if the contour sensor was traversing uphill or downhill. This instrument was subsequently tested by the Army Map Service and was rejected as unsuitable for their operations.

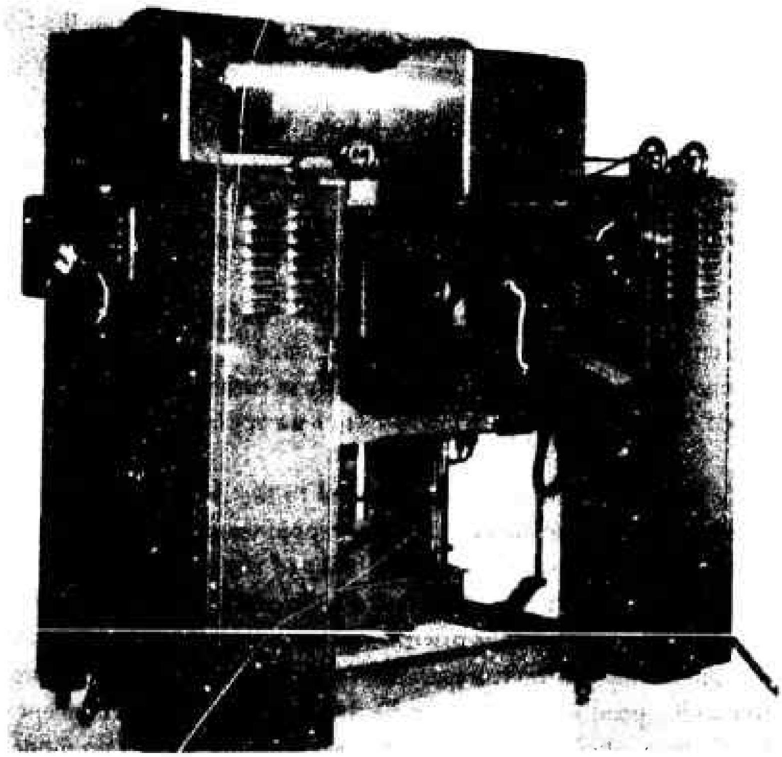

Fig. 76. Semi-automatic model making machine, Kaiser Aircraft and Electronics Corporation (1958).

During the course of this development, the concept of a fully automatic, terrain model-making machine based on a voltage-coded equivalent map source

was advanced by the Kaiser Aircraft and Electronics Corporation. Although military characteristics for such a device were drawn up in coordination with CONARC, development was not of sufficient priority and the ERDL program for development of terrain, model-making methods was terminated.

e. **Surveying and Geodesy Accomplishments — World War II to 1960.**

(1) **Theodolites.** At the close of World War II, work was still in progress on the development of a 1-second theodolite of domestic manufacture. During the early post World War II period, two other theodolite developments were initiated. The development of a 10-second, directional-type theodolite to replace the conventional, 20-second, repeating type and the establishment of a domestic source of supply were approved in October 1945. In October 1947, a project was approved to develop a 1-minute theodolite, which was to be a compact, lightweight, dust-proof, night-illuminated optical-reading instrument for use in general-purpose military survey work to replace the 1-minute transit then in use.

Inspection and tests of the 1-second theodolites produced by the W. & L.E. Gurley Company and the Keuffel and Esser Company in the closing days of World War II showed that the theodolites produced by the W. & L.E. Gurley Company were generally unsatisfactory, but the instruments produced by the Keuffel and Esser Company met the basic requirements and were considered satisfactory (Fig. 77). However, the Keuffel and Esser Company, because of the difficulties encountered and the expense involved, was no longer interested in producing a 1-second theodolite. Therefore, the W. & L.E. Gurley Company was contracted in 1947 to produce an additional experimental model and five service test models in accordance with revised specifications. The National Bureau of Standards was engaged to produce the graduated glass circles.

Acceptance and engineering tests of the experimental theodolite were completed in September 1950[136] and the five service test instruments were accepted later that year (Fig. 78). During the period from 1951 to 1953, cold weather tests[137,138] were conducted at Fort Churchill, Canada, and the 1-second theodolite was service tested under the supervision of Army Field Forces Board No. 2.

Although this program did eventually develop a domestically produced 1-second theodolite, the cost of production could not compete with cost of

136"Theodolite, 01-Second," ERDL Report 1207, 13 June 1951.

137"Cold Weather Testing of 1-Second Direction Theodolite, 10-Second Direction Theodolite, Universal Tripod and Astronomical Attachment," ERDL Report 1223, 5 January 1952.

138"Cold Weather Testing of 10-Second Direction Theodolite, 1-Minute Direction Theodolite, 1-Second Direction Theodolite (Foreign Model) Astronomical Attachment and Winterization Kit," ERDL Report 1288, 29 April 1953.

Fig. 77. Keuffel and Esser 1-second theodolite, pilot model (1946).

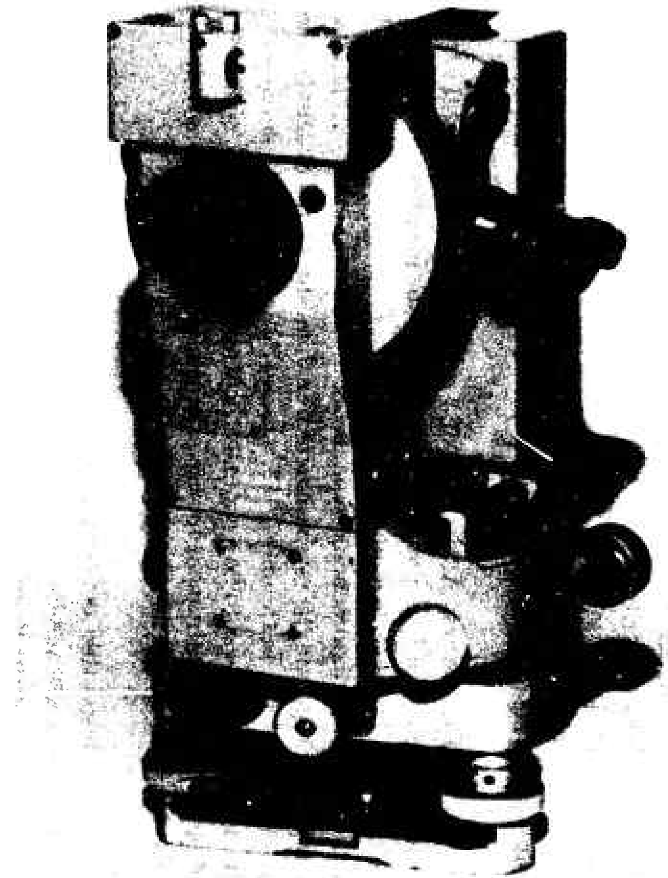

Fig. 78. Gurley 1-second theodolite, experimental model (1950).

procurement frum European manufacturers. Therefore, on 2 July 1954 almost 14 years after initiation of the development of the 1-second theodolite on 25 July 1940, the development project was officially cancelled by Corps of Engineers Technical Committee action.

The development of the 10-second theodolite pursued a relatively normal and uneventful course, drawing initially on the technology developed in the program on the 1-second theodolite and finally on technology developed in the concurrent 1-minute theodolite development. The Keuffel and Esser Company, Hoboken, New Jersey, pruduced an experimental model which was delivered to ERDL for test in May 1947 (Fig. 79). After some modifications to pruvide a more serviceable instrument, engineering tests were completed in 1949[139] and Keuffel and Esser Company was contracted to pruduce six service test models. Since the Keuffel and Esser Cumpany was also wurking on the 1-minute theodolite development by this time, it was possible to incorpurate applicable features of the 1-minute instrument design into the service test mudels and thus provide desirable modifications.

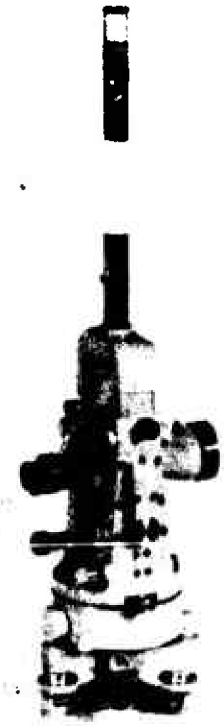

Fig. 79. Keuffel and Esser 10-second theodolite experimental model (1947).

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[139] "Theodolite, 10-Second," ERDL Report 1100, 28 January 1949.

All development and test work on the 10-second direction theodolite was completed in 1953. Arctic winter tests at Fort Churchill, Canada[140] in January 1951, desert summer tests at Yuma Test Station in Yuma, Arizona, in August 1952,[141] and service tests by the Army Field Forces had been done.

The development of the 1-minute theodolite was destined to pursue a rather rocky course as did the 1-second theodolite development. After the production of an experimental model by the Keuffel and Esser Company (Fig. 80) and completion of engineering tests[142] in 1950, a contract was awarded to the David White Company in May 1950 for two service test models. A short time later, the contract was modified to

Fig. 80. Keuffel and Esser 1-minute direction theodolite, experimental model (1949).

[140] "Cold Weather Testing of 1-Second Direction Theodolite, 10-Second Direction Theodolite, Universal Tripod, and Astronomics Attachment," ERDL Report 1223, 5 January 1952.

[141] "Hot Weather Testing of 10-Second Direction Theodolite With Universal Tribrach and Univeral Tripod, Astronomical Attachment, Universal Lens Compass, Lensatic Compass, and Wrist Compass," ERDL Report 1289, 29 April 1953.

[142] "Theodolite, 1-Minute," ERDL Report 1197, 1 May 1951.

call for circle graduation in the mil system for one of the instruments on order. The completion of this contract was delayed due to difficulty encountered by the contractor in graduating the circles. Therefore, in January 1953, the Keuffel and Esser Company was contracted to furnish glass circles graduated in the mil system; and, in February 1953, a supplemental sgreement was negotiated with the David White Company to furnish glass circles for the mil theodolite. Subsequently, in June 1953, a supplemental agreement was negotiated with the David White Company to deliver the mil-reading theodolite complete except for the glass horizontal and vertical circles.

In the meantime, pre-acceptance inspection and test of the 1-minute theodolite indicated that the David White Company could meet the accuracy requirement of the instrument center only with considerable difficulty and that quantity production problems were inevitable. To avoid this, ERDL negotiated with the Brunson Instrument Company to fabricate a new type ball-bearing center for both the mil reading and degree reading theodolites.

One service test model 1-minute theodolite with the new type hall bearing center and Government furnished glass circles was finally shipped to Army Field Forces Board No. 1, Fort Bragg, North Carolina, for service testing on 9 June 1954. The second service test model theodolite with mil graduations was shipped to CONARC Board No. 2, Fort Sill, Oklahoma, for service testing on 1 February 1955. Service testing was completed in November 1955. After evaluation of service test reports, OCE requested ERDL to investigate the feasibility of providing a telescope with an erecting optical system. This investigation revealed that a complete redesign would be necessary to provide an erecting telescope that would transit the full 360° and that this would be very costly and time-consuming. The results of this investigation were discussed with representatives of the Continental Army Command and OCE on 1 May 1957. As a result of information developed at this conference, it was concluded that further modification and tests of the service test model theodolites with a view to their eventual production by American industry would not be the most expeditious, economical, and productive approach to meeting Army troop user requirements. Therefore, it appeared advisable to consider procurement of a suitable foreign built surveying instrument.

Eventually, after testing of modified Wild T-16 theodolites equipped with mil circles, the Wild T-16 Theodolite (Theodolite Directional, 0.2 Mil, 5.0-Inch Long Telescope) was type classified standard in September 1958. Type classification of Theodolite, Directional, 1-Minute, 5.9-Inch Long Telescope, was accomplished early in 1960 and the project was closed.

It should be noted here that, in the early 1960's, the Brunson Instrument Company, Kansas City, Missouri, was the successful bidder on a quantity

procurement of 1-minute theodolites thus providing a domestic source for this instrument in compliance with Corps of Engineers specifications (Fig. 81).

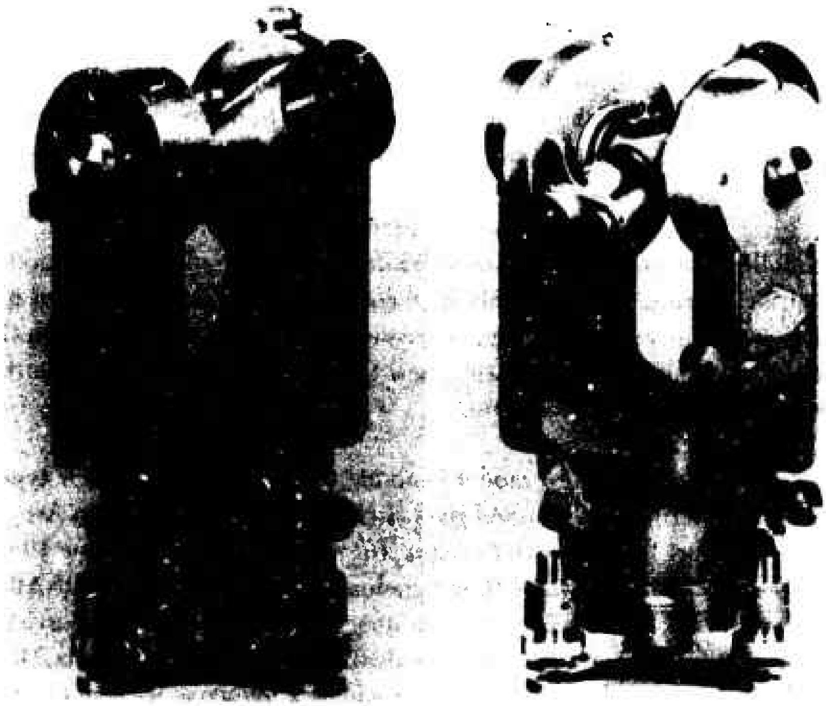

Fig. 81. The Brunson 1-minute theodolite.

(2) **Survey Computers.** The effort to develop a survey computer continued in the post World War II period and throughout most of the 1950's. In 1957, Army Regulation AR 1-250 assigned R&D responsibility for electronic data processing and computing equipment required for Army use to the Chief Signal Officer. However, the Chief of Ordnance was assigned the same responsibility for such equipment developed for and integral to weapons fire control systems. After this, specific development of computing equipment by ERDL was discontinued; however, the problem of selecting and developing software for computing equipment for surveying and mapping applications still remained.

As previously noted, a survey computer was first attempted in World War II and was unsuccessful, resulting in termination of a contract with the W. L. Maxon Corporation in January 1944. It is interesting to note that a similar development was again attempted in 1951 with like results. This effort was to develop a lightweight, hand-operated computer suitable for use by a traverse party to compute survey coordinates as measurements are completed. A development contract was awarded to Industrial

Research Institute, University of Chattanooga, Chattannoga, Tennessee, in December 1951 for an experimental model. The contract ran into mechanical malfunction difficulties and was subsequently cancelled. Following this, several manufacturers indicated an interest in developing a transistorized portable computer, but this approach was never pursued since CONARC did not re-affirm its requirement for development by this approach and the project was cancelled in December 1957.

The development of an electric survey computer was initiated in March 1947. International Business Machines Corporation developed an experimental model which was delivered to ERDL in January 1949 (Fig. 82). Engineering[143] and service tests[144] of this computer indicated a need for a more versatile computer, and as a result revised requirements were prepared.

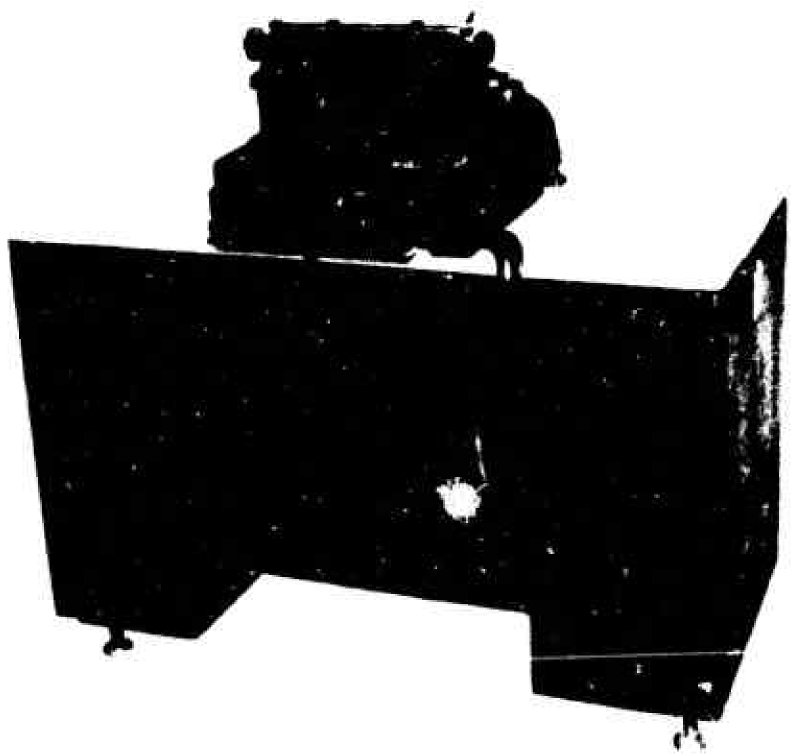

Fig. 82. Experimental electric survey computer, International Business Machines Corporation (1949).

143. "Computer Survey Electric (IBM)," ERDL Report 1146, 3 September 1949.

144. "Test of Computer, Survey, Electric and Surveying Equipment, Mobile Control Section," CONARC Board 2 Report P-1434, 8 January 1951.

In February 1952, Monroe Calculating Machine Company undertook the development of an experimental service test computer under the new requirements and the computer was delivered in February 1955 (Fig. 83). After engineering and service tests, this computer was transferred to the Army Map Service in January 1957 at their request.

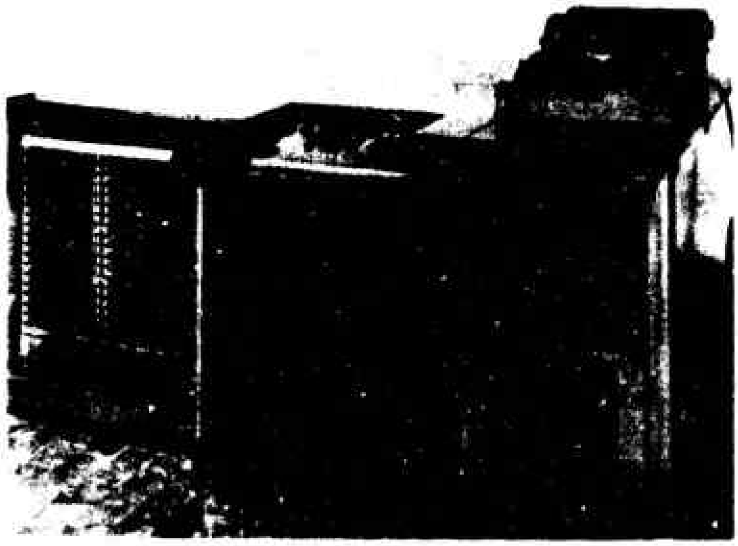

Fig. 83. Experimental electric survey computer, Monroe Calculating Machine Company (1955).

Following the testing of the Monroe Computer in August 1956, ERDL recommended adoption of revised military characteristics to reflect the current military requirement for an electronic computer. A service test model with characteristics similar to the RECOMP I, developed for the U.S. Air Force by Autonetics, a division of North American Aviation, was procured. The procurement was initiated by transfer of funds to Rome Air Development Center in June 1957 and subsequent contract by Rome Air Development Center with AVCO Manufacturing Corporation, Lawrence, Massachusetts. This effort aborted in February 1959 when the Rome Air Development Center terminated its contract with AVCO for the CP-266 computer, thus essentially ending ERDL efforts in the computer development field.

(3) **Compasses.** The development of compasses, both the wrist and the lensatic types, was reopened in 1947 to provide instruments which would overcome the deficiences noted in those developed during World War II. Experimental models of the lensatic compass were produced by Taylor Instrument Company, Rochester, New York (Fig. 84), and the Brunson Instrument Company, Kansas City, Missouri. Both were found to conform to the military characteristics, but the Brunson model was considered

Fig. 84. Experimental model lensatic compass, induction damped, Taylor Instrument Company (1948).

Fig. 85. Wrist compass, induction damped, 1949 model.

superior.[145] Experimental models of the wrist compass were produced by the Brunson Instrument Company, Kansas City, Missouri (Fig. 85), and were delivered to ERDL in January 1950.[146] Cold weather tests of the lensatic compass[147] were conducted at Fort Churchill, Canada, and in January 1951 service test models were procured and shipped to service test agencies. Here again, as with the compass development during World War II, emergency procurement of large quantities of both compasses was made before all testing and development had been completed.

Development of both compasses was completed in 1952.[148] The lensatic compass was classified as standard type, and the project was closed in June 1952. The wrist compass was classified as standard type, and the project was closed in November 1952.

(4) **Mobile Survey Control Section.** As a result of wartime experience which indicated that time would be saved and efficiency increased by providing a mobile survey control headquarters, a project was initiated in 1947 to develop such an item. It was to consist of a van-type truck or trucks containing the drafting and computing

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145 "Compass, Lensatic," ERDL Report 1154, 6 January 1950.

146 "Compass Wrist," ERDL Report 1183, 5 October 1950.

147 "Cold Weather Test of the Sun Compass and Lensatic Compass," ERDL Report 1181-L, 22 September 1950.

148 "Lensatic Compass," ERDL Report 1250, 2 September 1952.
"Compass, Wrist," ERDL Report 1266-L, 28 November 1952.

facilities and the communication and control center of the survey elements of Engineer Topographic companies and battalions.

Although engineering and user tests of the mobile survey control section were completed by 1956, it was not until 1960 that type classification action was completed and the project was closed. In part, the delay was caused by difficulties encountered in the development of a computer for the section. The final result of the development was a single, van-type truck mounted on a standard ordnance truck chassis and incorporating standard air conditioner and heating equipment. It contained the necessary office furniture, computing and drafting equipment, supplies, and radio communication equipment to operate a field computing section of a survey platoon.

(5) **Electronic Distance Measuring Equipment.** Work on the development of methods and techniques for the best use of ground survey electronic equipment in establishing control for mapping started in 1947. At that time, the Director of Research and Development, WDGS, directed the Chief of Engineers to prepare military characteristics and a plan of development for "Ground Survey Electronic Surveying Equipment and Methods." The Chief of Engineers forwarded military characteristics to the Director of Research and Development in June 1947 and recommended that the Signal Corps undertake the development of ground electronic surveying equipment and the Corps of Engineers initiate a project to provide methods for the use of such equipment.

The Signal Corps development resulted in the design and fabrication of an experimental model AN/PPN-13 electronic distance measuring equipment, two models of which were completed in January 1952 (Fig. 86). These were tested on the bench and in the field in 1952. In May of that year, the Signal Corps Engineering Laboratories contracted with Motorola, Inc. for 14 sets of the equipment. This system was based on a pulse technique wherein a distance was measured by the elapsed travel time of a large number of pulses of electromagnetic energy from master to remote station and return.

Over the next few years, the Signal Corps Engineering Laboratories continued to modify circuitry on the experimental models to produce suitable results, until in April 1955, after almost 3 years of effort, it was agreed that a change in approach was necessary to expedite the delivery of service test models. Not until December 1958 was one AN/PPN-13 system delivered to ERDL. In the meantime, developments in the phase-comparison system area had overtaken the Signal Corps development. The AN/PPN-13 was tested in Northern Virginia. Since the equipment was considerably heavier, bulkier, and less accurate than the phase-comparison systems which had become available by this time, further work on the development of the pulse system was dropped.

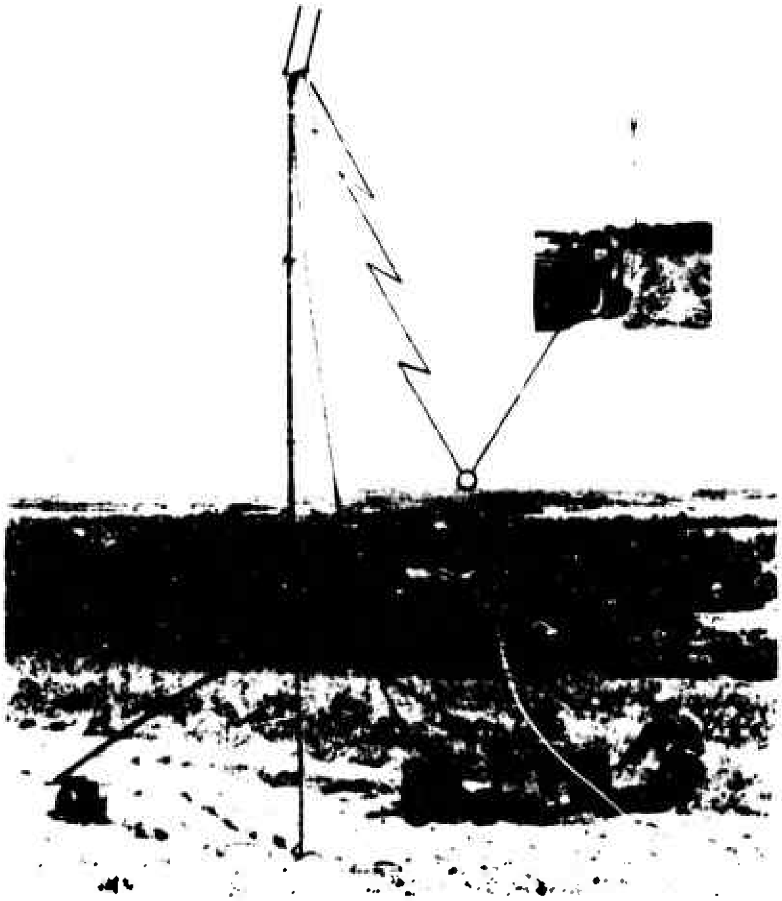

Fig. 86. AN/PPN-13 electronic distance measuring equipment, Motorola, Inc. (1956).

During this time, ERDL was investigating other ranging systems for possible military application. In 1954, the "Raydist System Type O" of the Raydist Navigation Corporation was tested in the Caribbean over distances ranging from 65 to 175 miles. After these tests, a program was set up to evaluate radio continuous wave phase comparison systems as a means of measuring long distances up to 500 miles. These investigations and field tests were made by the Lorac Service Corporation in the 1955 to 1957 period.

In March 1957, a contract was awarded to the Lorac Service Corporation extending the scope of previous contract work and requiring optical and radio-optical azimuth and distance determination in a test net in Arizona where ranges were 70 to 86 miles. In this work, some experiments also took place in positioning ground and air vehicles using the Lorac system as a radio locating system.

In December 1957, a contract was awarded to Seismograph Corporation for studies, reconnaissance, and tests involving distances and azimuth over water for ranges from 100 to 500 miles. The contract also included the development of an electronic azimuth indicator. By 1959, this work and all manuals on the Radio Continuous Wave Phase Comparison System (LORAC) were completed. Three special long-range transmitters and an experimental azimuth measuring system had also been finished.

The development of the Tellurometer, a phase-comparison, microwave, distance-measuring system, in the Union of South Africa came to the attention of ERDL in the mid-1950's. After initial investigation, sets were ordered from the developer, Tellurometer, Union of South Africa, for ERDL, Army Map Service, U.S. Geological Survey, and the U.S. Coast and Geodetic Survey in December 1956 (Fig. 87). These were delivered to ERDL in March and April 1957 and were immediately tested in combined engineering and service tests at Leesburg, Virginia, and Yuma, Arizona, in the period April through June 1957. The final result was the adoption and type classification of the M/RA-1 Tellurometer System in June 1958.

Although the Tellurometer was type classified in 1958, efforts continued to provide militarized and miniaturized equipment. In March 1958, a contract was awarded to Tellurometer Ltd to develop an Airborne Tellurometer System, and in June 1958 a contract was awarded to Tellurometer Ltd for modified M/RA-1 systems to be of rugged, moistureproof, and dustproof construction and with an almost exclusive use of American made components. In October 1958, the contract was modified to

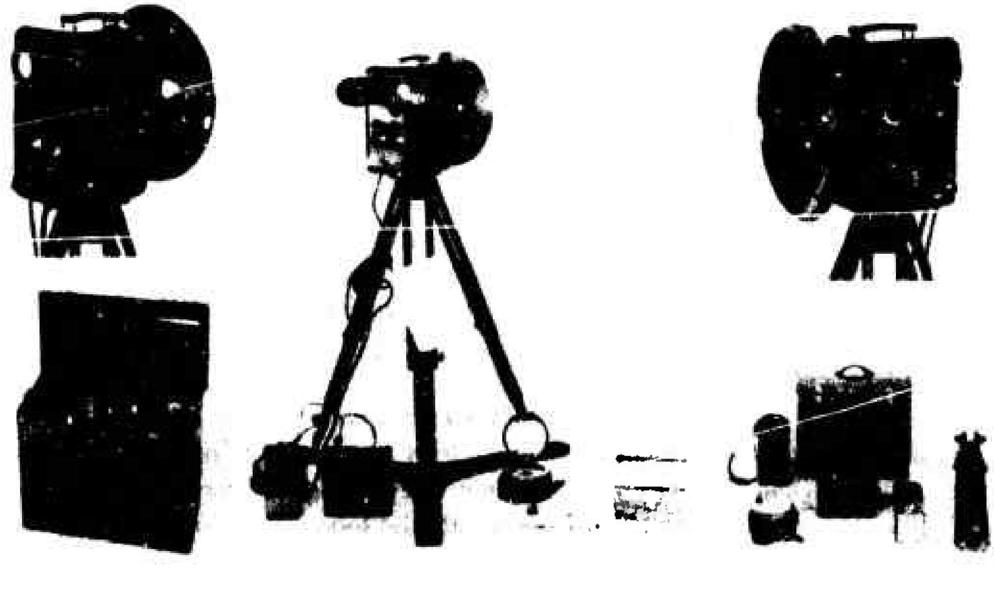

Fig. 87. Tellurometer, master set and auxiliary equipment, 1957.

include a dual, master-remote function for each unit. Tellurometer was also contracted in December 1958 to develop portable, short-range electronic positioning equipment. The airborne equipment was delivered for test in 1959, and the portable equipment was successfully demonstrated in August 1959.

To develop a domestic source for the electronic ranging equipment, a contract was awarded to Cubic Corporation, San Diego, California, in June 1958. In 1959, Cubic Corporation was contracted for miniaturized electronic ranging equipment (Fig. 88). Engineering tests of the Cubic equipment in 1959 showed it to be a suitable domestic equivalent to the Tellurometer system (Fig. 89).

Fig. 88. Micro-dist equipment, Cubic Corporation (1959).

ELECTROTAPE TELLUROMETER

Fig. 89. Advanced models of the Electrotape produced by the Cubic Corporation and the Tellurometer produced by Tellurometer, Ltd.

(6) **Geodimeters.** While the development of electronic distance-measuring surveying instruments was in progress in the 1950's, parallel investigations were being made of another distance-measuring system, the Geodimeter (invented in Sweden). This equipment, designed to operate in the visible frequency range, employs a light transmitter-receiver at one end of the line to be measured and a retrodirective mirror or prism system at the other.

ERDL had been following the development of the Geodimeter in Sweden before approval of a Geodimeter development project in February 1951 to adapt the system to military field use for precise baseline measurement for triangulation.

When the Geodimeter, manufactured by the AGA Svenska. AB. Gasaccumulator, Stockholm, Sweden, became available commercially, five instruments were procured by ERDL in 1953 and were distributed to the U. S. Coast and Geodetic Survey, the Ballistics Research Laboratories, and the Army Map Service for test. Two were retained at ERDL. These five instruments were designated Geodimeter Model I.

During the next several years, modification and improvements were made in the Geodimeter system, including the development of a retrodirective prism

system by ERDL which was superior to the system which was supplied by the AGA Company. In addition, the AGA Company produced an improved version, the Model II (Fig. 90), later designated the 50-kilometer Geodimeter.[149] In 1954, a Model III lightweight Geodimeter of lesser accuracy was demonstrated by the AGA Company, and in December arrangements were made to purchase four of these for test. This was later designated the 30-kilometer Geodimeter. Finally, to provide a man-portable device for quickly and accurately measuring distances up to 3 kilometers in length, the AGA Company developed the Model IV Geodimeter. A contract was awarded to Berg Hedstrom Company, New York, for four of these instruments in May 1957. One was delivered in November 1957, one in January 1958, and two in July 1958.

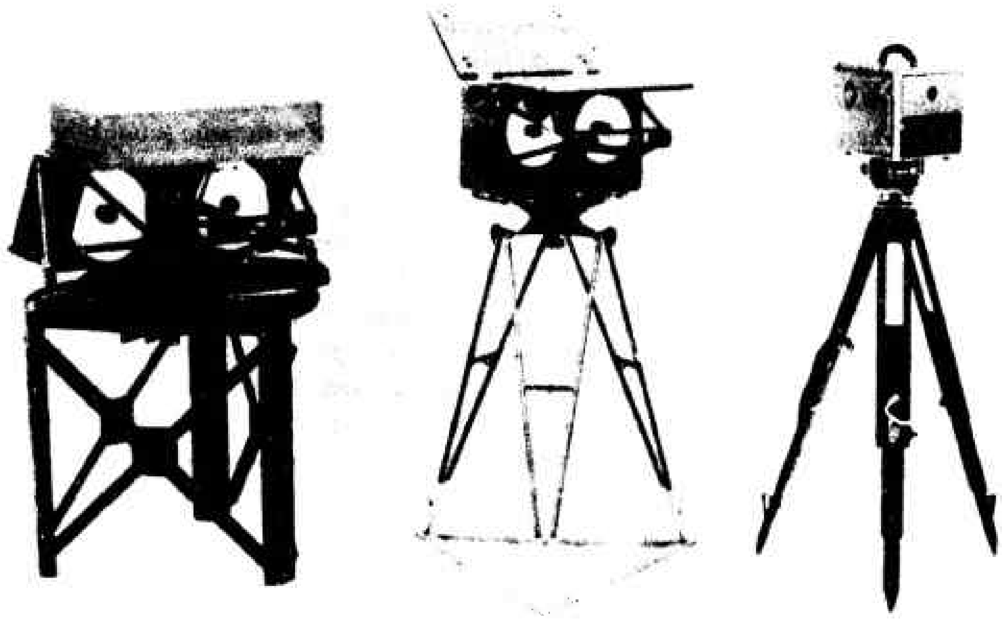

Fig. 90. Geodimeters: Models II, III, and IV (1957).

The major advantage of the Geodimeter over other distance-measuring systems was the precision and accuracy of measurement. A major disadvantage for military application was its limitations for daylight use, depending as it did on frequencies in the visible range. Type classification action on the 50-kilometer Geodimeter was taken in 1958. Later work on the 30-kilometer Geodimeter was suspended, as was work on the 3-kilometer Geodimeter, pending final evaluation of the miniaturized tellurometer as discussed earlier.

149 "Geodimeter Models I and II," ERDL Report 1495-TR, 21 August 1957.

Through these programs, the Corps of Engineers played a key role in the development of advanced precision distance measuring instrumentation which was destined to revolutionize surveying practices in many and diverse applications in the years to come.

(7) Use of Aircraft in Survey Operations. The use of aircraft to facilitate survey operations and provide methods and techniques to substantially increase the rate of extending ground survey control over difficult terrain or long distance was a subject for specific investigation beginning in the immediate post World War II period and extending through the 1950's.

Initial investigations concerned use of a helicopter as a visible signal for horizontal and vertical direction observations. First tests of these techniques in cooperation with the Air Force started in September 1946 and continued through August 1947.[150] These tests demonstrated feasibility. Further tests with more suitable helicopters were planned but were delayed because of unavailability of aircraft until 1952 when tests were conducted to determine the feasibility of extending horizontal control by flare triangulation using an L-20 type aircraft for transporting the signal and flares. Major items in these tests were modified Wild T-3 Theodolites, robot cameras, SCR #624 radio sets, 2.5-kva generators, a special target light, and M-8-A/1 parachute flares. It was concluded from these tests[151] that the procedures and applications used were generally suitable for use by topographic survey units for establishing third-order triangulation extensions and provided material advantagea over conventional methoda when operations were conducted over difficult terrain. Subsequently, Army helicopters and light aircraft were authorized as organic equipment for certain survey units, primarily for transport and reconnaissance applications.

Further tests of the helicopter as an elevated target for intersection and resection triangulation were conducted in Arizona in 1953 using an H-19-C Army Helicopter. Tests were also conducted using an H-13 Helicopter. Investigations of a light-beam controlled helicopter for use as a stabilized elevated target also took place in the mid-1950's through a contract with Koman Aircraft Corporation. Through a contract with Altoscan Company, Inc., an engineering study of means for stabilized tethering of helicopters was conducted. Later in 1957, through a Navy contract with Altoscan Company, ERDL participated in research for an elevated target or relay station for electronic surveying equipment.

By 1959, investigation of the use of aircraft in survey operations was associated principally with other development projects such as the Artillery Survey

150. "Helicopter Survey Methods for Mapping," ERDL Report 1044, 15 March 1948.

151. "Helicopter Survey Methods for Mapping (Flare-Signal Triangulation Test)," ERDL Report 1230, 19 May 1952.

System, Airborne Tellurometer, Automatic Tracking Theodolite, the LORAC project, etc. Therefore, no other specific investigations of helicopter applications were made.

(8) Automatic Position Survey Equipment. In an effort to increase the speed of determination of a first-order geographic position, a project was approved in December 1956 to develop automatic position survey equipment. In June 1957, a contract was awarded to the Mechanical Division of General Mills, Inc., Minneapolis, Minnesota, to: (a) conduct preliminary studies and modifications of existing astronomic equipment for interim use, (b) provide manuals and engineering services in connection with testing, operating, and maintaining the interim equipment, and (c) prepare detailed design drawings of the final equipment.

The contractor selected the 60° pendulum astrolabe for the interim item and developed plans to modify the instrument to provide an automatic leveling system, an inertial reference system, and an electronic star transit system. After repeated delays and cost overruns finally amounting to about 64 percent over the original estimate, the equipment was fabricated and delivered to ERDL in July 1959 just before the demonstration of the Interim Artillery Survey System (Fig. 91). Initial testing, limited to eight observations in 5 weeks due to inclement weather, yielded unsatisfactory results.

Fig. 91. Automatic Position Survey Equipment Observation Instrument.

Fig. 92. Automatic Position Survey Equipment Computer and Typewriter.

However, after some minor modifications and further tests at the contractor's facility in October 1959, the equipment was accepted (Fig. 92). However, Phase III, the design of a final first-order equipment, was eliminated from the contract.

(9) **Automatic Tracking Theodolite.** Another effort to increase the speed of survey operations in the field and to provide for implementation of advanced methods of illuminated aerial target and artificial satellite triangulation was the development of an automatic tracking theodolite approved by GSUSA in February 1958. Two parallel study contracts were awarded to General Electric and General Mills, Inc., to design an automatic tracking theodolite. Before these contracts could be completed, the responsibility for the Artillery Survey System was assigned to the Corps of Engineers for expedited development. These studies were broadened to include a system of automatic tracking theodolites suitable for artillery survey operations.

After evaluation of these studies in the last quarter of 1958, a contract was awarded to General Mills, Inc., for a survey system for artillery using Automatic Tracking Theodolites (Fig. 93). This capability was to be the extension of geodetic control to 12 unknown stations in an area 40 miles square to an accuracy of 1:5000. Automatic Tracking Theodolites were fabricated under this contract in 1959 and were tested in 1960. After these limited tests in which the technical feasibility of the

Fig. 93. Automatic Tracking Theodolite.

automatic tracking theodolite was established, further development for artillery surveys was dropped in favor of the electronic ranging approach.

(10) Artillery Survey System. In May 1958, the Chief of Research and Development, Department of the Army, assigned to the Chief of Engineers overall development cognizance of the Artillery Survey System and requested expeditious development of the projects comprising the system under priority 1A. At the same time, the Chief of Ordnance was officially advised of this assignment of responsibility and was requested to establish liaison with the Chief of Engineers to describe the extent of work done on the project and to make available information, records, or equipment relating to the project as desired by the Chief of Engineers. The Chief Signal Officer was also advised of this assignment of responsibility and was requested to work with the Chief of Engineers as required in connection with the data transmission. The project for this development was approved in September 1958. This was the first use of an organized effort to apply an overall systems approach to the solution of a surveying problem as opposed to the individual item development approach.

The objective of the project was to provide a rapid survey system as fully automatic in operation as possible to fulfill field artillery requirements in all-weather, day and night operations. An immediate objective was to demonstrate an experimental system employing the maximum number of components envisioned for the complete system by 1 August 1959.

An Artillery Survey System demonstration was held on 4 August 1959 at Clark Mountain, Orange County, Virginia. All related items of the system were

presented in various stages of completion from mockups to models ready for type classification. The interim system as demonstrated included the Survey Control Center, Jukebox Computer, T-2 Theodolite, Tellurometer, Orienter, Recom II Computer, Short Range Electronic Positioning Equipment, Airborne Tellurometer, 3-km Geodimeter, Automatic Position Survey Equipment, and Automatic Tracking Theodolite (Fig. 94).

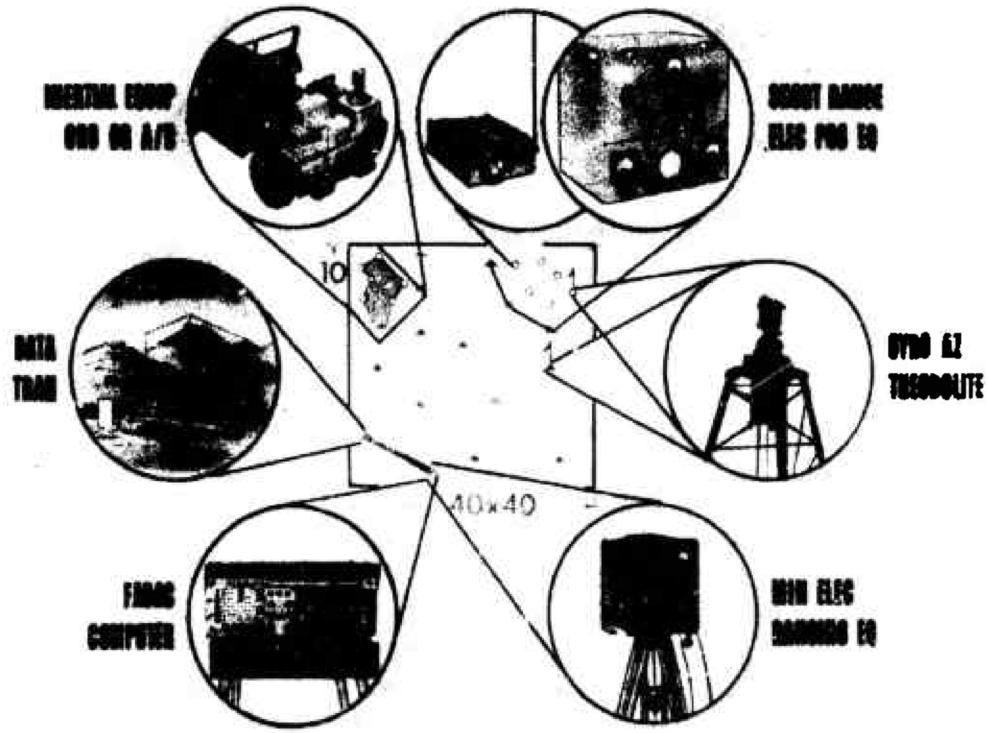

Fig. 94. Artillery Survey System.

(11) **Inertial Survey Equipment.** The development of inertial survey equipment by the Corps of Engineers was started in 1958 when, as a result of assignment of development responsibility for the Artillery Survey System to the Chief of Engineers, the Ordnance Corps on 12 August 1958 transferred to ERDL an Ordnance contract for the ABLE gyro-orienter. The orienter was being developed by the Autonetics Division of North American Aviation, Inc.

The project for inertial survey equipment development was approved in October 1958, and in November 1958 the ABLE orienter was delivered to ERDL. After user testing at Fort Sill, Oklahoma, the orienter was classified standard by CETC on 6 November 1959.

In August 1959, the Corps of Engineers was assigned full responsibility for the development of all gyro-orienting devices except that required by the Pershing missile system. Prior to this, in April 1959, a contract was awarded to Kearfott Company, Clifton, New Jersey, for a gyro-azimuth theodolite for Engineer use.

In June 1959, ERDL had contracted with the Missiles and Space Vehicles Department of General Electric Company for preliminary design of inertial survey equipment, and late in 1959 negotiations were initiated with General Electric for the fabrication of this equipment. Late in 1959, negotiations were initiated for a lightweight, reconnaissance, gyro-orienting device.

(12) **Miscellaneous Developments.** Numerous other items were developed or worked on in the late 1940's and through the mid-1950's. The more significant of these are discussed in the following paragraphs.

(a) **Astronomic Orientation Attachment.** During the development of an astronomic orientation attachment by the W. & L.E. Gurley Company, Troy, New York (which was delivered to ERDL in 1945), a new device (Shattuck) was discovered which indicated advantages over the W. & L.E. Gurley device. An experimental model of this new device was constructed by the U.S. Naval Observatory, Washington, D.C., and delivered to ERDL in 1945. Engineer tests of both models indicated marked advantages for the new model. Some new principles were also discovered during testing, and and a third model was constructed by the David White Company, Milwaukee, Wisconsin (Fig. 95), and delivered to ERDL in June 1948.[152] Later, service test models were procured and tested by Army Field Forces and the Marine Corps in 1950 to 1952. After Arctic[153] and desert tests[154] in 1952 and incorporation of required modifications in specifications and drawings, the item was classified standard type 4 in June 1954 and the project was closed.[155]

(b) **Radio Time Comparator.** In 1946, an experimental model Radio Time Comparator was fabricated; and after engineering tests, 42 of the units were

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152 "Astronomical Attachment, Azimuth Determination, Reflecting, for Transit and Theodolite," ERDL Report 1120. 13 May 1949

153 "Cold Weather Testing of 01-Second Direction Theodolite, 10-Second Direction Theodolite, Universal Tripod and Astronomical Attachment," ERDL Report 1223, 5 January 1952.
"Cold Weather Testing of 10-Second Direction Theodolite, 1-Minute Direction Theodolite, 1-Second Direction Theodolite (Foreign Model), Astronomical Attachment, and Winterization Kit," ERDL Report 1288, 29 April 1953.

154 "Hot Weather Testing of 10-Second Direction Theodolite With Universal Tribrach and Universal Tripod, Astronomical Attachment, Universal Sun Compass on Wrist Compass," ERDL Report 1289, 29 April 1953.

155 "Astronomical Attachment, Azimuth Determination, Reflecting, for Transit or Theodolite," ERDL Report 1374, 3 September 1954.

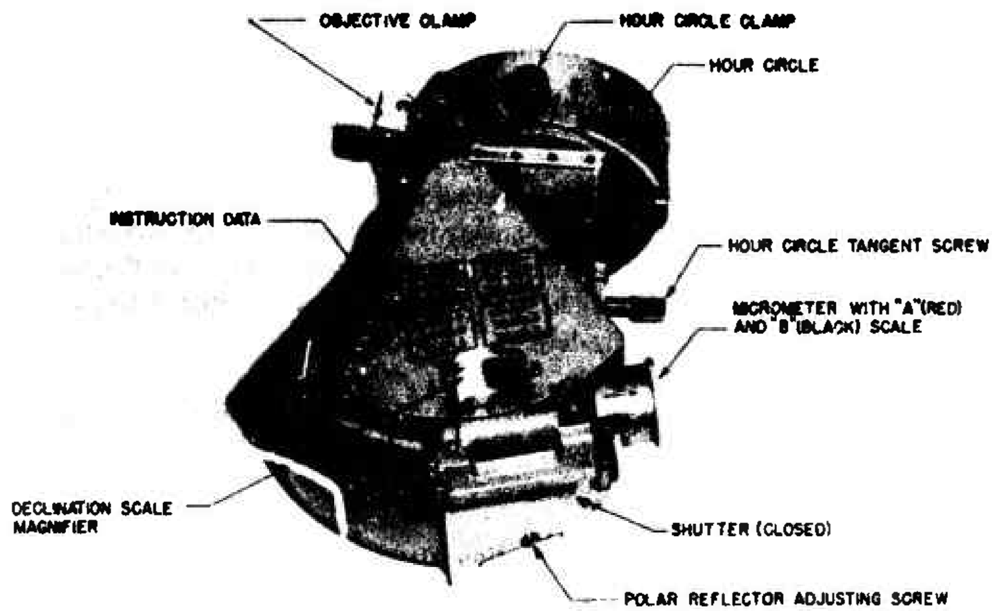

Fig. 95. Astronomic Orientation Attachment, David White Company, 1948.

procured from the W. M. Welch Company, Chicago, Illinois, for use in the Post Hostilities Mapping Program. The item was tested by the topographic units participating in that mapping program and also by the Air Forces and the Army Field Forces. ERDL performed additional tests for final evaluation. After all tests were completed, it was finally concluded that: (1) the Radio Time Comparator, although basically sound in principle, was not suitable for universal field use; (2) an electromechanical means of determining chronometer error was not warranted in the standard astronomic position equipment set ENG-6 120-01; and (3) the manual method of determining chronometer error with an automatic timer was more dependable and more consistently accurate in timing star transits than an electromechanical time comparator when used with the observing equipment.[156] The project was cancelled 6 July 1951.

(c) Surveying Altimeter. A project was initiated in October 1947 to develop a surveying altimeter of greater accuracy and range than those developed in World War II. It was to have sufficient range for leveling up to 15,000 feet altitude (4500 meters) (Fig. 96). Experimental models were fabricated by Wallace and Tiernan Products, Inc., Belleville, New Jersey, and were delivered to ERDL in June 1949.[157] After service testing of 21 service test models procured in 1950, modifications were incorporated as recommended, including graduation in the metric system. Five additional

156."Radio Time Comparator," ERDL Report 1193, 19 March 1951.

157."Altimeter, Surveying, 15,000-Foot, 5-Foot Divisions," ERDL Report 1152, 6 December 1949.

models were produced by Wallace and Tiernan for test.[158] The project was finally completed in May 1954 when Altimeter, 4500 Meter, 2-Meter Divisions, was classified standard type and the project was closed.

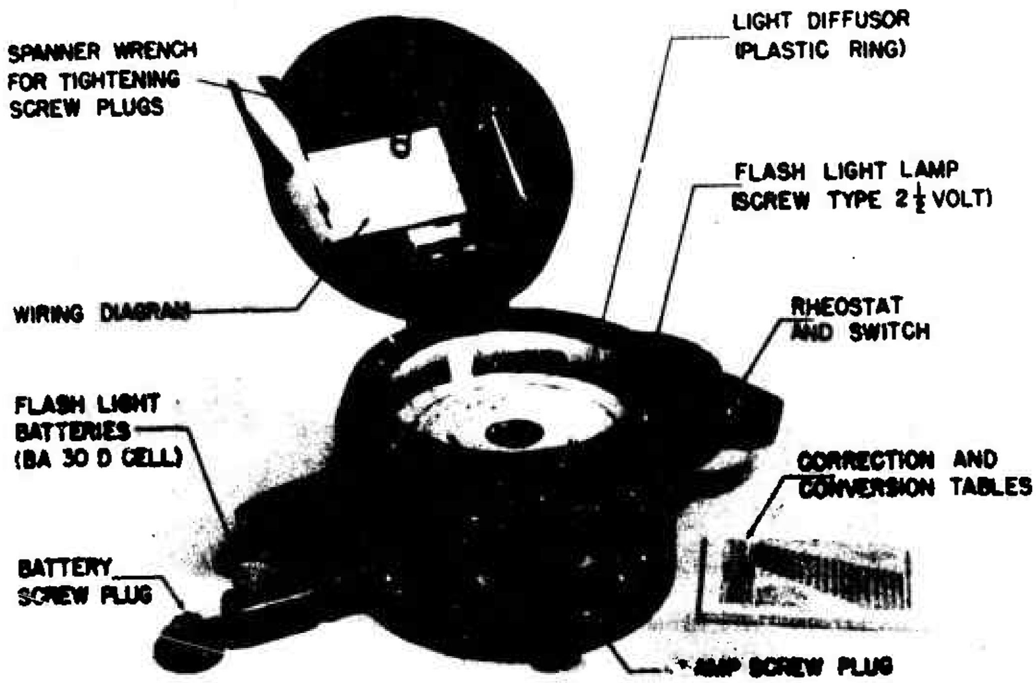

Fig. 96. Surveying Altimeter, 4500 Meter.

(d) **Universal Sun Compass.** In 1947, a project was approved to develop an improved sun compass that could be used in all latitudes, as opposed to the instrument suitable only between latitudes 45° north and south. Experimental and service test models were made by the Brunson Instrument Company, Kansas City, Missouri (Fig. 97).[159] Arctic winter tests were conducted at Fort Churchill, Canada, in February 1950.[160] Desert tests were conducted at Yuma Test Station, Yuma, Arizona, in August 1952,[161] and the project was closed 4 June 1954.

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158. "Altimeter, Surveying, 4500 Meters, 2-Meter Divisions," ERDL Report 1350-L, 2 June 1954.

159. "Compass, Sun, Universal, 0-90 Degrees North and South Latitudes, With Cases," ERDL Report 1153, 6 January 1950.

160. "Cold Weather Tests of the Sun Compass and Lensatic Compass," ERDL Report 1181-L, 22 September 1950.

161. "Hot Weather Testing of 10-Second Direction Theodolite, With Universal Tribrach and Universal Tripod, Astronomical Attachment, Universal Sun Compass, Lensatic Compass, and Wrist Compass," ERDL Report 1289, 29 April 1953.

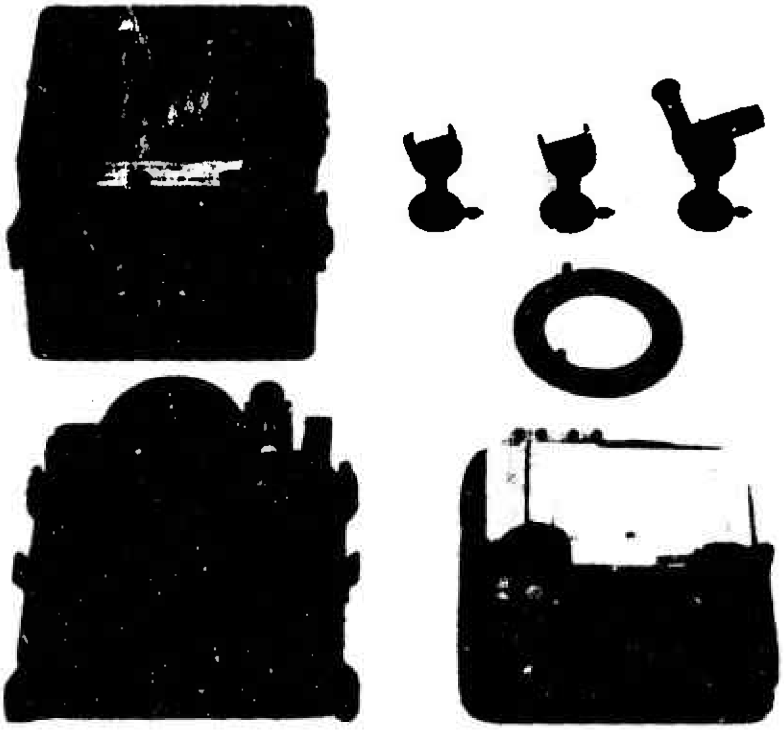

Fig. 97. Universal Sun Compass, 0° to 90° north and south latitudes.

(e) **Tripods and Tribrachs.** On 3 October 1947, projects were approved by General Staff, U. S. Army, to develop a universal tripod and a universal tribrach to standardize the mounting of surveying instruments which use tripods thus simplifying operations and the supply problem. Experimental and service test models of the universal tripod[162] were fabricated by the Keuffel and Esser Company. Experimental and service test models of the universal tribrach[163] were fabricated by the W. & L. E. Gurley Company. Cold weather tests of the tripod were conducted at Fort Churchill, Canada, in January to February 1951.[164] Hot weather tests of both the tripod and the tribrach were conducted at Yuma Test Station, Yuma, Arizona, in July to August 1952.[165] Neither item attained separate classification status, but detailed drawings and specifications were prepared. Both projects were closed by CETC action on 7 January 1955.

162. "Tripod Universal," ERDL Report 1202, 21 May 1951.

163. "Tribrach Universal," ERDL Report 1112, 8 April 1949.

164. "Cold Weather Testing of 1-Second Direction Theodolite, 10-Second Direction Theodolite, Universal Tripod, and Astronomical Attachment," ERDL Report 1223, 5 January 1952.

165. "Hot Weather Testing of 10-Second Direction Theodolite With Universal Tribrach and Universal Tripod, Astronomical Attachment, Universal Lens Compass, Lensatic Compass, Wrist Compass," ERDL Report 1289, 29 April 1953.

(f) **Ranging Pole Tripod.** The Ranging Pole Tripod was developed, tested, and adopted in the period from 1950 to 1952[166] to provide a lightweight, adjustable tripod for setting and plumbing range poles in combat survey operations. The tripods were needed because survey parties are frequently required to place and plumb ranging poles rapidly and then to take cover while observations are being made. Experimental and service test models were fabricated in the ERDL shops. The item was included as a component in applicable sets of equipment, and the project was closed by CETC action on 5 December 1952.

(g) **Triangulation Tower.** Another of the early post World War II[167] projects was the development of a lightweight triangulation tower to replace the Bilby Tower which was too heavy to meet many operational requirements. This project was approved in February 1947.

An experimental model was designed and fabricated by the Aerometer Company, Chicago, Illinois (Fig. 98).[168] Service test models were fabricated by Wind Turbine Company, West Chester, Pennsylvania. Three of these models were shipped to the Inter-American Geodetic Survey for test and three were sent to engineer units on the west coast for test. All development and test work was completed in 1952[169] and the tower was included in Surveying Set, Signal and Tower, in lieu of the steel Bilby Tower.

(h) **Indirect Distance Measuring.** In 1952, a project was initiated to investigate and evaluate for military use methods and equipment to indirectly determine the length of survey traverse courses by optical surveying instruments and auxiliary devices. Very little progress in this project occurred although tests were conducted using available foreign and domestic equipment at ERDL. In 1953, a Wild Tachymeter was procured for test. This project was overtaken by developments in the electronic distance measuring area, and it was terminated 3 August 1956.

(13) **Research for Surveying and Geodesy.** In 1958, it was recognized that although some advances were being made in surveying and geodetic equipments and methods; these equipments and methods would not provide acceptable survey control and geodetic data for use with missiles or in the production of topographic maps because of excessive lead time and new problems introduced under current concepts of military operations. Therefore, intensive research was required to discover new phenomena and

166 "Tripod, Ranging Pole," ERDL Report 1199, Interim Report, 11 May 1951.

167 "Tripod, Ranging Pole," ERDL Report 1238-L, Final Report, 10 June 1952.

168 "Tower, Triangulation, Lightweight," ERDL Report 1145, 30 September 1949.

169 "Tower, Triangulation, Lightweight," ERDL Report 1239, 26 June 1952.

Fig. 98. Triangulation Tower, Lightweight.

principles to advance the state-of-the-art in the field of surveying and geodesy to overcome these limitations. A project was approved on 1 August 1958 to research various scientific fields to determine, establish, or develop new criteria, phenomena, facts, principles, or techniques to apply in the development of new or improved methods or equipment for surveying in military operations, including employment of Army missiles. A supplemental allocation of funds was made available to ERDL to implement this program.

Three contracts were awarded in 1958. One was to the University of Maryland to provide consultant services for the program.[170] Under this contract, a

[170] This team also provided consultant services for research on map compilation as previously noted.

team comprised of Professor Frederick J. Doyle of Ohio State University; Dr. Paul Herget, Director of the Cincinnati Observatory, Cincinnati, Ohio; and Dr. Sanford Goldman of Syracuse University met periodically with ERDL and contract personnel to provide advice and guidance on the conduct of individual research programs.

Another contract was awarded to the Franklin Institute, Philadelphia, Pennsylvania, for studies of extraterrestrial data as an aid to mapping and position determination. The third contract was awarded to Midwest Research Institute to study the effect of natural electromagnetic and geomagnetic forces on advanced methods of target location, precise surveying, and mapping.

The Franklin Institute Studies included sighting geometry and error propagation in satellite observations including the simultaneous case, the almost simultaneous case, and the nonsimultaneous case. The geometry for 16 basic nonredundant cases for simultaneous satellite sighting for geodetic purposes together with a set of equations for error analysis for one of the 16 cases, target objects, observing instruments and techniques, and the geodetic potential of existing satellite tracking data were also studied. The program further considered studies that would lead to choice of specific locations for satellite observation stations for geodetic ties; error propagation for the specific case of the 12 Baker-Nunn camera stations; study of value of a multipath satellite; optimum brightness and color in a satellite; photoelectric occultation of stars; and the use of geodetic satellite procedures to improve star catalogs.

The Midwest Research Institute studies included analysis of inertial navigation errors caused by gravitation anomalies; the influence of the earth's curvature on radio wave propagation; and the effect of the troposphere on use of electromagnetic waves in geodesy. Effects of the ionosphere on Doppler signals from satellites, and ionosphere cross modulation were also studied. A basic study of space mensuration to determine the applicable and proper statistical theories and methods for geodetic measurements using artificial earth satellites; interaction of electromagnetic waves in the ionosphere; experimental proof of Doppler satellite tracking methods for geodetic operations; and analytical investigations of satellite orbit perturbations also were considered.

These research studies continued through 1959 and into the 1960's.

20. Research and Development Progress 1960 to 1970.

a. Introduction. At the beginning of the 1960's, the mapping and geodesy research and development program of the Topographic Engineering Department of ERDL comprised five basic projects with 36 subprojects. A number of these subprojects were in the final stages of completion. The project structure at that time was as follows:

8T35-03-001 <u>Map Compilation</u>

Engineering Studies and Investigations, Map Compilation

Stereoplotter, Topographic, Projection Type, High Precision

Rectifier, Photogrammetric, 9 by 18-inch Photography

Processing Equipment, Diapositive, for Stereophotogrammetric Mapping Requirements

Map Revision Techniques

Orthographic Photogrammetric Printer

Army Photo Imagery Interpreters Kit

8T35-09-001 <u>Map Reproduction</u>

Engineering Studies and Investigations, Map Reproduction

Xerography, Application to Map Reproduction

Separator, Color, Scanning, Topographic Map

Target Map Coordinate Locator Equipment

Cartographic Drafting Methods and Equipment

Photo Lettering Machine

8T35-10-001 <u>Surveying and Geodesy</u>

ES&I, Surveying and Geodesy

Surveying Equipment, Mobile Control Section

Theodolite, 1 minute

Use of Army Aircraft in Survey Operations

Computer, Survey, Electric

Utilization of Ground Survey Electronic Equipment for Mapping

Automatic Position Survey Equipment

Geodimeter, 3-Kilometer Range, for Measuring Distances by Light Waves

Theodolite, Automatic Tracking

Artillery Survey System

Inertial Survey Equipment

8T35-11-001 Combat Mapping and Geodetic Systems

ES&I, Combat Mapping and Geodetic Systems

Liaison with Air Force on Aerial Mapping Systems

Target Location for Army Surface-to-Surface Missiles

Mapping with Minimum Ground Control

Analytical Photogrammetry

Utilization of High Altitude Photography for Mapping

Automatic Map Compilation

Ultra Wide Angle Photography in Mapping, Equipment and Techniques for the Utilization of

Utilization of Radar Presentations for Topographic Mapping

8T35-12-001 Mapping and Geodetic Research

Research for Surveying and Geodesy

Research for Map Compilation

Research for Map Reproduction

At the beginning of the 1960's, the technology in the topographic sciences area was at the point in the surveying and geodesy area, where electronic distance measurement was well established as a working tool. The feasibility of the application of inertial techniques to the solution of surveying problems had been fairly well established, and the potential in the application of satellites for the solution of geodetic problems had been evaluated. A variety of techniques for satellite exploitation had been proposed. In the map compilation area, the feasibility of automatic compilation of contoured orthophotomaps from overlapping stereoscopic aerial photography had been demonstrated, precision optical stereoscopic plotting instrumentation was in advanced stages of development, the techniques were available for the analytical adjustment of large blocks of photographs in aerotriangulation, and the development of computer programs and the instrumentation required for exploitation of these techniques was in progress. Development effort directed toward the automation of cartographic operation was just beginning as was the development of systems for mapping from radar presentations. In the map reproduction and presentation areas, the feasibility of the electrostatic reproduction of topographic maps had been demonstrated. As a result, the concept of map reproduction at point of use and on demand in lieu of advanced quantity map reproduction for areas of predicted military operations was formulated.

Increased interest in and funding for research and development in the mapping and geodesy areas began in the late 1950's because of advances in missile and earth satellite technology which placed greater demands for speed and accuracy in the production of geodetic and mapping data. Expanded programs of research were implemented and, while programs for the development of equipment and techniques for application by field Army units which had been the main thrust of programs through the 1950's continued, the effort was expanded to explore and advance development in the strategic systems area toward base plant application. Some programs were directed specifically toward the provision of specialized equipment for the new Army Precision Photogrammetric Laboratory constructed at Army Map Service.

After the establishment of GIMRADA in August 1960, programs were formulated in the geographic sciences area to solve problems of acquisition and to process and disseminate terrain intelligence information in advance of and during military operations.

In the early 1960's, there was a general restructuring and renumbering of Department of Defense research and development programs. Programs were classified in four stages of development: Research (6.11), Exploratory Development (6.21), Advanced Development (6.31), and Equipment Development (6.41). As a result of this restructuring, the shifts in emphasis, and the implementation of new programs during the 1960's, the program structure and the projects undertaken during the mid- to late 1960's were as follows.

R&D PROGRAM FOR OFFICE, CHIEF OF ENGINEERS

RESEARCH: 6.11

4A061101A91D	In-House Laboratory Initiated Research and Development
4A061102B52C	Mapping and Geodetic Research
-01	Cartography
-02	Geodesy
4A061102B52D	Research in Geographic Sciences

EXPLORATORY DEVELOPMENT: 6.21

4A623501A852	Mapping and Geodetic Research
-01	Research for Surveying and Geodesy
-02	Research for Map Compilation
-03	Research for Map Reproduction
-04	Utilization of Computer Sciences for Mapping and Geodesy (Initiated in FY 71)
4A623501A853	Mapping and Geodesy Development
-01	Engineering Studies and Investigations, Global Mapping and Geodesy*
-02	Liaison With Air Force on Aerial Mapping Systems
-04	Utilization of Satellite Data for Geodesy
-05	Utilization of Satellite Data for Mapping*
-06	Analytical Photogrammetry
-07	Automatic Map Compilation
-10	Utilization of Advanced Sensors for Mapping
-11	Utilization of Auxiliary Airborne Data for Mapping*
-12	Mapping From Reconnaissance Photography*
-13	Digitized Terrain Data*
-14	Micromap System for Display Systems*

*Project completed, suspended, or renumbered during the decade 1960-1970.

-15	Automatic Cartography
-16	Utilization of Color Photography for Mapping
-17	Automatic Pattern Recognition
-18	Classified
4A062112A854	Military Geographic Analysis (start date 07/65)
-01	Analysis of MGI Requirements and Definition of Systems Concept
-02	MGI Data Collection (start date 07/66)
-03	MGI Data Reduction (start date 07/66)
-04	MGI Product and Analysis Definition (start date 07/66)
-05	MGI Data Handling (start date 07/66)

ADVANCED DEVELOPMENT: 6.31

4A663712D855	Global Mapping and Geodesy
-03	Digitized Terrain Data Equipment
-04	Geodetic Satellite System
-05	Reconnaissance Photo Data Reduction Equipment
-08	Map Reproduction from Miniaturized Material (start date 07/67)
-09	Map Compilation System (start date 07/67)
-10	Analytical Triangulation Programs
4A663712D860	Military Geographic Systems (start date 07/68)
-03	Military Geographic Intelligence (MGI) Products, Displays and Readouts (start date 07/68)
-04	Military Geographic Intelligence Data Base (start date 07/68)
4A663712D861	Worldwide Topographic System Data Bank (start date 07/70)
4A663712D863	Topographic All-Weather Mapping System (start date 06/68)
4A663712D864	Semi-Automatic Cartographic System (start date 07/67)

EQUIPMENT DEVELOPMENT: 6.41

4A664716D866	Topographic All-Weather Mapping System (start date 07/69)

EXPLORATORY DEVELOPMENT: 6.21

1J662707A576	Field Army Mapping and Surveying
-01	Engineering Studies and Investigations, Field Army Mapping and Surveying
-05	Distance and Angle Measuring Equipment (start date 07/67)
-06	Imaging Materials Studies

ADVANCED DEVELOPMENT: 6.31

1J663712D673	Field Army Surveying
-01	Miniaturized Gyro Compass
-05	Position and Azimuth Determining System

ADVANCED DEVELOPMENT: 6.41

1S66433I5D577	Field Army Map Reproduction Equipment*
-01	Engineering Studies and Investigations, Field Army Map Reproduction Equipment*
-03	Xerography, Application to Map Reproduction*
-05	Target Map Coordinate Locator Equipment*
-07	Field Army Map Reproduction and Distribution System*
1S643315D578	Surveying Equipment for the Field Army*
-01	Engineering Studies and Investigations, Surveying Equipment for the Field Army*

Automatic Position Survey Equipment
Miniaturized Gyrocompass
Angle Measuring System Electronic
Inertial Surveying System
FADAC Programs for Surveying Problems

*Project completed, suspended, or renumbered during the decade 1960-1970.

-12	Long Range Survey System, Light Weight*
	Long Range Survey Equipment Surveying Instrument, Gyro Azimuth, Light Weight
-13	Elevation Determining System, All-Weather*
-14	Angle Measuring System, All-Weather*
-15	Quaser Surveying System*
-23	Miniaturized Gyro Compass*
-24	Inertial Surveying Systems*
-27	Distance and Azimuth Determining System*
1J664716D578	Surveying Equipment for the Field Army
-12	Long Range Position Determining System (start date 03/61)
-23	Miniaturized Gyro Compass (start date 06/71)
1S643315D579	Field Army Mapping Systems*
-01	Engineering Studies and Investigations, Field Army Mapping Systems*
-03	Rapid Combat Mapping System*
-11	Multipower Army Stereoscope*
1J664716D579	Field Army Mapping Systems
-03	Rapid Combat Mapping System (RACOMS)

Under these research and development programs, some rather remarkable technological advances were made in the mapping and geodesy area, the most significant of which will be described in the remaining sections of this history. However, it should be noted that while the research and development programs of the 1960's continued to address the problem of surveying and mapping in the field by troop units under combat conditions, a rather large portion of the program was designed to address the problems of the collection, processing, and dissemination of topographic data on a global basis. Up to the 1960's, the controlling requirements for topographic information were generally based on the needs of so-called conventional artillery which required relatively high accuracy over short distances. The advent of long-range missiles and airborne vehicles of various sorts brought the additional requirement for accuracy over intercontinental distances. Better knowledge of the size and shape of the earth, the position of points thereon, and of the earth's gravity field was required to provide missile guidance. New

*Project completed, suspended, or renumbered during the decade 1960-1970.

concepts of military operation developed unprecedented demands for processing and disseminating large volumes of topographic and geographic information for almost any part of the world.

b. **Basic and Exploratory Research.** At the beginning of the 1960's, there was virtually no basic research program in the topographic mapping and geodesy area. The major effort in the exploratory research area was embodied in three contracted research efforts: (1) investigations in fields of science relating to mapping, geodesy, and position determination by the Franklin Institute, Philadelphia, Pennsylvania; (2) research on instrumentation of satellites and other hypersonic vehicles for precise surveying, mapping, and target location by the New York University Research Division; and (3) research to determine the effects of natural phenomena on present and contemplated methods of precise surveying, mapping, and target location and where possible to develop new concepts for topographic operations by the Midwest Research Institute, Kansas City, Missouri.

With the establishment of GIMRADA in August 1960, a research and analysis division was set up as one of the six operating divisions of that organization. This division was responsible for developing a viable research program and organizing a competent staff to carry out that program. The concept at that time was to establish within the organization a competent staff of senior scientists of recognized stature in several disciplines such as physics, astronomy, mathematics, geodesy, and geophysics. Each scientist would pursue research tasks within the general overall area of interest of GIMRADA for which he was specially qualified and in which he had a particular interest. He would be supported in these efforts with outside contractual efforts by universities or other research establishments as the situation required.

While recruitment of personnel was in progress and in view of the short supply of available manpower, a program of basic research by competent scientists in Europe was actively pursued, implemented, and supported through the U.S. Army European Research Office. Under this program, research contracts were let to Professor K. B. P. Hallert, Royal Institute of Technology, Stockholm, Sweden; Professor A. Bjerhammer, Head of the Department of Geodesy, Royal Institute of Technology, Stockholm, Sweden; Dr. C. Morelli, Bari University, Director of Geophysical Laboratory, Trieste, Italy; Professor K. Ledersteger, Technical University, Vienna, Austria; and Professor W. Grossman Technical University, Hanover, Germany. Later, the research of Professor K. Rinner, Technical University, Graz, Austria, was supported through the U.S. Army European Research Office.

The research effort of Professor Hallert was on the theory of errors in photogrammetry. This research for the most part was carried out while Professor Hallert

was in residence at GIMRADA for about 1 year starting in October 1961. The research produced seven GIMRADA research notes.[171-177]

The research of Dr. Morelli, supported to the mid-1960's, was on the refinement and interpretation of gravity anomaly computation.[178] The research of Professor Grossman was on the propagation problems of electronic distance measurement specifically with the electrotape equipment to understand better the corrections to be applied to measurements made under adverse conditions.[179] The research program of Professor Ledersteger was concerned with the development of new methods for determination of the earth ellipsoid based on additional parameters of densities and interior structure, or model figures of equilibrium that most closely fit the structures and the shape of the earth. This research which was aimed at increasing our knowledge of the earth's constants and internal structure through effects on satellite orbits and the application of laws of rotating fluids in equilibrium continued to the late 1960's and was funded in part by the U.S. Army European Research Office. It produced a series of technical reports on the development of the Ledersteger theory.[180] [181] [182]

The research of Professor Bjerhammer (including a 6-month period in residence at GIMRADA from June to December 1963 and, in 1966, a brief tour as Director of the Research Institute of Geodetic Sciences, GIMRADA) was aimed at better

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171 RN-1, "Practical Tests of the Theoretical Accuracy of Aerial Triangulation," May 1962.

172 RN-3, "Determination of the Geometric Quality of Comparators for Image Coordinate Measurements," August 1962.

173 RN-4, "Investigation of Basic Geometric Quality of Aerial Photographs and Some Related Problems," August 1962.

174 RN-5, "Test of Basic Geometric Qualities of Photogrammetric Plotting Instruments," August 1962.

175 RN-6, "Investigations of the Geometric Quality of Relative and Absolute Orientation Procedures and the Final Results of the Photogrammetric Procedure," August 1962.

176 RN-7, "Some Relations Between the Geometric Quality of Topographic Mapping and Aerial Photogrammetry," August 1962.

177 RN-9, "Geometric Quality of Lunar Mapping by Photogrammetric Methods," September 1962.

178 Final Report, "Research on Refinement and Interpretation of Gravity Anomaly Computations," Correzzo, M. T., and Morrelli, C., July 1967.

179 Final Report, "Investigation of the Electronic Distance Measuring Equipment Electrotape," Grossman, W., December 1964.

180 Final Report, "Multi-Parametric Figures of Equilibrium; Curvature of the Plumb Line," March 1964.

181 Final Report, "Multi-Parametric Theory of Spheroidal Equilibrium Figures and the Normal Spheroids of Earth and Moon," June 1966.

182 Final Report, "Equilibrium Figures and the Normal Spheroid of the Earth Mass Functions and Isostacy," April 1968.

gravity data reduction and the development of a figure of the earth based only on horizontal distances between observational points, gravity, and potential differences. The results of this research are recorded in several research papers published by Professor Bjerhammer, GIMRADA, and the Royal Institute, Stockholm, Sweden.[183-187] Also, while Professor Bjerhammer was Director of the Research Institute he formulated the concept for an automatic electro-optical satellite triangulation system.[188]

The research of Professor Rinner of the Technical University, Graz, Austria, which was initiated in 1964 and continued into 1967, was concerned with geodetic networks in space. This included a study in error propagation in space triangulation and space trilateration systems and combination of angle and distance measurements applied over large areas.[189] This work gave insight into the behavior of a global trilateration as accomplished by the SECOR program. Other research efforts in the early 1960's, while the staff of the Research and Analysis Division was being developed, included the development of a photo flash triangulation concept under contract with Geonautics, Inc., Washington, D. C.[190] and a continuation of work started in 1959 on the theoretical analysis of the effects of supersonic and hypersonic aircraft speed upon aerial photography by Vidya Inc., Palo Alto, California.[191] Also, the research program of New York University on the instrumentation of satellite and other hypersonic vehicles for precise surveying and target location[192] and another study on space photogrammetry[193] were completed.

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[183] Final Report, "On an Explicit Solution of the Gravimetric Boundary Value Problem for an Ellipoidal Surface of Reference," A. Bjerhammer, February 1963.

[184] RN-12, "Gravimetric Geodesy Free of Density Estimates Through Analysis of Discrete Gravity Data," A. Bjerhammer, December 1963.

[185] Royal Institute of Technology, Stockholm, Final Report, "Investigation of Bjerhammer's New Gravity Reduction Method," W. Forstner, November 1964.

[186] Royal Institute of Technology, Stockholm, Final Report, "Studies of Gravity in Space According to Bjerhammer," B. G. Reils, April 1966.

[187] American Geophysical Union, Washington, D. C., "A New Geoid," A. Bjerhammer, April 1967.

[188] RN-23, "An Automatic Electro-Optical Satellite Triangulation System," A. Bjerhammer, April 1967.

[189] K. Rinner, "Systematic Investigation of Geodetic Networks in Space," Final Report, March 1967.

[190] H. Eichorn, "Photogrammetric Flash Triangulation for Corps of Engineers Field Use," Final Report, August 1961.

[191] "Effects of Supersonic and Hypersonic Aircraft Speed Upon Aerial Photography," Interim Report, August 1959, July 1960, October 1960.

[192] "Research on Instrumentation of Satellite and Other Hypersonic Vehicles for Precise Surveying, Mapping, and Target Location," Final Report, New York University, February 1961.

[193] "Research in Space Photogrammetry," Final Report, New York University, October 1961.

The Midwest Research Institute contract[194] was extended into the mid-1960s to include techniques to determine the integrated refraction index of the atmosphere between two points and ultimately to design an experiment to verify the inverse scattering theory developed in this research.[195]

The Franklin Institute contract implemented in late 1958 was converted to a longevity funded effort in the early 1960's and included studies in several and varied areas of interest until contract termination in the mid-1960's. The final report was submitted in October 1960.[196] Under the longevity funded effort, series of studies and reports were submitted from 1960 through 1965. These studies included the evaluation of components for some elevation-determining system,[197] application of advanced accelerometers to surveying and geodesy,[198] atmospheric refraction,[199] a pilot program of lunar photography[200] in which photographs of the earth-lit moon were taken at selected observation points around the world in an effort to provide better sensor data for lunar mapping than the few photographs in current use, lunar mapping from a high altitude balloon, and the application of the coriolis force to geodetic measurement.[201]

With the addition of specialists in geodesy, physics, astronomy, and mathematics to the Research and Analysis Division staff in the early 1960's, research activity began to be oriented around the individual scientist's skills and interests as they related to the overall GIMRADA mission. The earliest results of this approach were two studies relating to atmospheric refraction, a problem which had been addressed both by the Franklin Institute and the Midwest Research Institute in previous research studies. The results of these studies were published in separate GIMRADA research notes.[202] [203]

194 "Research Studies Related to Mapping, Geodesy, and Position Determination," Midwest Research Institute, Interim Reports December 1960, December 1961, June 1961, September 1961, March 1962, June 1962, October 1962, Final Report January 1963.

195 "The Design of a Laser Experiment for the Verification of the Inverse Scattering Theory," Midwest Research Institute.

196 "Research in Surveying, Mapping, and Geodesy," Final Report, Volume I, Parts 1 and 2, October 1960.

197 "Evaluation of Components for Some Elevation Determining Systems," Interim Report, Franklin Institute, May 1963.

198 "Application of Advanced Accelerometers to Surveying and Geodesy," Interim Reports, Franklin Institute, Volume I, November 1963, Volume II, March 1964.

199 "Refraction in Selected Model Atmospheres," Interim Report, Franklin Institute, February 1964.

200 "A Pilot Program of Lunar Photography for Precise Selenodesy," Interim Report, Franklin Institute, October 1964.

201 "Application of Coriolis Force to Geodetic Measurements," Interim Report, Franklin Institute, December 1965.

202 A. A. Baldini, RN-8, "Formulas for Computing Atmospheric Refraction for Objects Inside or Outside the Atmosphere," January 196[illegible].

203 H. H. Schmid, RN-10, "The Influence of Atmospheric Refraction on Directions Measured To and From a Satellite," February 1963.

By 1962, Dr. Baldini had begun his research on Theory of World Geocentric Geodetic System, commonly referred to as the Baldini Theory. Work on this theory continued throughout the decade of the 1960's. It provides a basis for expressing the positions of points around the earth in a common system referred to the center of mass of the earth, based on new theoretical concepts for defining astronomical position of ground points with respect to satellite positions against a star background. The absolute deflection of the vertical is also obtained independently of gravity data. A special lunar-stellar camera on an equatorisl mount was developed under contract by the Autometric Corporation in 1963 to be used in field verification of certain aspects of this theory. The results of this research have been reported in a number of GIMRADA research notes[204-208] and a series of technical papers presented at various technical conferences over the decade. The most significant of these papers were "Determination of Center of Mass and Mathematical Figure of the Earth Using Solely Astro-Geodetic Methods" presented at the IUGG, Switzerland meeting, 1967, and "Determination of Latitude and Longitude of Unknown Station from Photographs of a Satellite Against Stellar Background Independent of any Distance" presented at the Army Science Conference at West Point, New York, June 1970.

The only outside support to Dr. Baldini's research were a contract investigation and a test by Autometric Corporation in 1963 of a proposed method of geocentric position determination with star satellite photography from a single camera station,[209] and an evaluation of the stellar-moon camera system by the Ohio State University Department of Geodetic Sciences[210] in the 1966 to 1965 period.

Another in-house research program implemented in the early 1960's dealt with computation of long-line geodesics, geodetic trilateration, and triangulation intersection, and long-line azimuth and distance determination between non-intervisible points by E. M. Sodano. Mr. Sodano is known internationally for the development of the line-crossing method of long-line azimuth determination. Certain aspects of this research are

[204] RN-2, "New Formulas Useful When Changing Ellipoidal Parameter or Orientation," July 1962.

[205] RN-17, "New Method for Determining Azimuth and Latitude Independent of Time and Zenith Distance," February 1966.

[206] RN-19, "Determination of Direct and Inverse Azimuth, Zenith Distance Hour Angle, Declination and Distance Between Two Points on Normal Section," February 1967.

[207] RN-20, "Star Position Determined by Combining Micrometric Observation With an Observed Known Star in a Vertical Plane Close to the Meridian," February 1967.

[208] RN-32, "Satellite Geodesy Based on Stellar Orientation of Lines Between Unknown Stations," November 1969.

[209] "Geocentric Position and/or Orbital Parameters with Star-Satellite Photography from a Single Camera Station," Autometric Corp., November 1963.

[210] "An Evaluation of the Stellar-Moon Camera System," Ohio State University Department of Geodetic Sciences, June 1958.

reported in a GIMRADA research note[211] and in a number of technical papers presented at various meetings. This research has produced a new formulation of a geometric field method, improved and refined over the years, for obtaining the distances and vertical and horizontal directions of the earth chord joining distant ground stations using a combination of electronic ranging and optical observation of either one or two moving or stationary aerial targets. The most significant of the technical papers on this subject are: "Optical Electronic Azimuth and Range Between Non-Intervisible Distant Ground Stations," Army Science Conference 1964; "Supplement to Inverse Solution of Long Geodesis," Second International Symposium on Geodetic Calculation, Brussels, Belgium, June 1966; "Data Reduction for Long Aerial Lines of Relatively Low Elevation," Second International Symposium on Geodetic Calculations, Brussels, Belgium, June 1966; "Three-Dimensional Station Coordinates of Increasing Vertical Rigidity From Lower Airborne Target," ASP-ACSM Convention 1967; and "Optimum Three-Dimensional Geodetic Formulations and Applications," 1969.

In the physical science areas, the most significant research programs started in the early 1960's were the investigation of lasers for geodetic application, the study of atmospheric effects on electronic pointing and angle measurement, studies of Doppler tracking of artificial satellites for field army applications, and investigations of atmospheric effects on light waves; i.e., laser radiation.

The first continuous-wave laser obtained for laboratory investigation was procured from the Raytheon Company in January 1963. Initial research was concerned with techniques of modulation and demodulation of laser radiation and studies of coherency over various path lengths and types of terrain. Later, in June 1964, a low-power, continuous-wave gas laser with outputs in the visible (0.63 μ) and infrared (1.15 and 3.39 μ) was procured from Spectra-Physics, Inc. These early investigations formed the groundwork for later formulation of several highly significant applications of laser technology to problems of geodetic measurement.

The first of these was the application of the laser in an instrument designed for measuring the absolute acceleration of gravity,[212] a laser gravimeter, conceived in 1964. A feasibility model was constructed in-house in 1965; in May 1966, a contract was awarded to Barkley and Dexter Laboratories, Fitchburg, Massachusetts, for a high performance instrument. This instrument was successfully completed by 1970 and achieved a precision of better than one part in 1 million. It has a potential accuracy of 0.2 milligal. The instrument consists of a laser interferometer in which the measuring arm is vertical. The reflector terminating the measuring arm is dropped in a vacuum

211 RN-11, "General Non-Iterative Solution of the Inverse and Direct Geodetic Problems," April 1963.

212 K. D. Robertson, RN-18, "Instrument for Measuring Absolute Acceleration of Gravity," June 1966.

chamber and the interferometer fringes generated as it falls are counted for precise time periods. Another was the development of techniques for very precise surveying. A contract for an experimental model laser distance-measuring instrument was awarded to Spectra-Physics, Inc., in November 1965 and the instrument was delivered to GIMRADA in June 1967. As a result of intensive in-house field studies with this equipment of atmospheric parameters which pose a limit to surveying accuracy, techniques evolved during 1969 and 1970 have produced results as great as five times the accuracy previously obtainable.

Research in laser technology also led to the formulation of a concept for an ultra-precise geodetic baseline[213] which was proposed in 1967, and could lead to a redetermination of the velocity of light; and the production in-house in 1969 to 1970 for the Civil Works Division of the Office, Chief of Engineers, of instrumentation consisting of a laser projector and a novel centering detector which permitted the precise measurement of alignment both on top of and in the galleries of concrete dams.

To support the research on electronic angle measurement, GIMRADA funded a study by the National Bureau of Standards (NBS) at Boulder, Colorado, of various microwave techniques for measuring angles with emphasis on accuracy and compatibility with conventional microwave distance measuring instruments including atmospheric limitations and their dependence on antenna size. A report on these investigations, which started in September 1961, titled, "Atmospheric Errors in Microwave Range and Short-Baseline Azimuth Measurements" was submitted by NBS in April 1964. These studies under Dr. M. C. Thompson provided background information used by the Surveying and Geodesy Division in their development program on electronic angle measuring equipment. Work on atmospheric effects on electromagnetic radiation continued at NBS, Boulder, under GIMRADA sponsorship to mid-1965; the final report was submitted in December of that year. In mid-1965, GIMRADA and the U.S. Coast and Geodetic Survey implemented a joint program of sponsorship of research at NBS, Boulder, concentrating primarily on correction for atmospheric efforts on optical and electronic distance measurement. The research was primarily on the dual optical technique for refraction index correction to distance measurement.

Research and Analysis Division personnel became interested in and started investigations of the application of the U.S. Navy Doppler Satellite Navigation System, Transit, to field army survey problems early in 1961, and started to assemble components to put together a set of doppler tracking instrumentation for experimental purposes. This construction of a tracking station was later abandoned. Little progress was made in this investigation until May 1964 when a contract was awarded to Westinghouse Electric Corporation, Baltimore, Maryland, for an experimental feasibility study using data

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213 K. D. Robertson, RN-24, "Concept for an Ultra-Precise Geodetic Baseline," November 1967.

obtained with U.S. Navy equipment on a noninterference basis. These investigations were completed and a report was submitted by Westinghouse in May 1965. The results were sufficiently encouraging that the procurement of backpack Doppler tracking equipment being developed at the time by the U.S. Navy was authorized for further experimentation, and this program moved from research to exploratory development by the Surveying and Geodesy Division.

In the midst of concerted efforts to build a viable research program and staff in the early 1960's, the Research and Analysis Division was called upon to make two special investigations in the satellite geodesy area for the Office, Chief of Engineers. While these special studies diverted attention from the planned research and development activity and in that sense were disruptive, they did familiarize the staff more intimately with some of the basic and realistic problems of satellite tracking applications to geodesy. In January 1962, the Chief of the Research and Analysis Division was called upon to form a special investigative team to evaluate the current Corps of Engineers Geodetic Satellite program which was embodied primarily in the Army Map Service program with the Sequential Collation of Range (SECOR) System and to advise as to future plans. This system, which had been under procurement by the Army Map Service from the Cubic Corporation, San Diego, California, had run into difficulty in the first efforts to track a satellite transponder, and there was some question as to the validity of the approach and the future role if any it should play in Corps of Engineers geodetic programs. An expedited investigation was requested. The team formed for this investigation consisted of personnel of the Research and Analysis Division: Dr. Frederick Rohde, Mr. Joseph Hannigan, and Mr. Emmanuel Sodano with Mr. John Pennington as head of the team; two electronic experts from the Ballistics Research Laboratories, Aberdeen Proving Grounds, Maryland: Dr. Keates Pullen and Mr. Richard Viteck; and an expert on electromagnetic radiation from the National Bureau of Standards at Boulder, Colorado: Dr. M. C. Thompson.

This special study was completed in 6 weeks, and a special report "Review and Analysis of U.S. Army Geodetic SECOR Development" was submitted to Office, Chief of Engineers. The report established the validity of the SECOR approach, analyzed the problems of development, and recommended a program for continued development by the Corps of Engineers. As a result, development responsibility was assigned to GIMRADA, and the evaluation team was retained in a technical advisory capacity in further development of the system.

A second special investigation came immediately on the heels of the SECOR investigation when, in March 1962, GIMRADA was requested to make a special expedited study of the Corps of Engineers minitrack activities and to determine an effective satellite geodesy program. The same SECOR team personnel augmented by Dr. Angel Baldini of the Research and Analysis Division staff comprised the new working

group formed for this investigation. The report of this group, "Tracking Systems for Geodetic Purposes," was submitted to Office, Chief of Engineers, in May 1962. It included analyses of various tracking systems including moon dual camera (Markowitz) and positioning of satellites against a star background and mathematics and data reduction for orbital analysis, theodeolite tracking, occulations, and electronic systems applicable to geodetic position determination.

With further augmentation of the Research and Analysis Division staff in the mid-1960's, several new programs of investigation and research were implemented. These new programs were generally in the areas of photogrammetric metrology and image evaluation, data reduction and analysis of geodetic satellite tracking data, calibration of both photographic and electronic data acquisition systems, research in solid state UHF amplifiers in support of the SECOR development, and studies of the geodetic applications of the torsion balance and gravity studies.

In the area of photogrammetric metrology and image evaluation, a study had been made in 1962 under contract with General Precision, Inc., Pleasantville, New York, on "Automatic Stereo Perception of Aerial Photography by Means of Optical Correlation."[214] In 1963, a comprehensive in-house program of investigation of visual factors involved in pointing precision and measurement was implemented under Mr. Desmond O'Connor. This research involved the in-house construction of special laboratory apparatus for measuring and recording visual performance data and also special apparatus for the controlled generation of edge gradients required for these and other investigations.

The visual factor investigations were augmented by studies of fusion and disparity limits for photogrammetry at Purdue University under Professor S. A. Veres,[215] studies of mono versus stereo analytical photogrammetry at the University of Illinois under Professor H. M. Karara,[216] studies of the role of focal length in image generation at Ohio State University, studies of pointing to a sharp edge at Washington University,[217] and studies of the effects of nonhomogeneous backgrounds on coordinate measurement at Purdue University.[218]

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[214] "Automatic Stereo Perception of Aerial Photography by Means of Optical Correlation," Final Report, General Precision Inc., December 1962.

[215] S. A. Veres, "Investigation of Fusion and Fixation Disparity Limits for Photogrammetry," Final Report, August 1965.

[216] H. M. Karara, "Mono Versus Stereo Analytical Photogrammetry," Final Report, Part I, February 1967. H. M. Karara and G. W. Marks, Part II, February 1968.

[217] K. Lund and J. E. Colcord, "Evaluation of Pointing to a Sharp Edge," April 1968.

[218] R. E. Roger and E. M. Mikhail, "Study of the Effects of Nonhomogeneous Target Backgrounds on Photogrammetric Coordinate Measurement," Final Report, August 1969.

The research on pointing and measuring precision as related to circular targets was virtually completed with the publication of Desmond O'Connor's Doctorate Dissertation, from the University of Illinois, as a GIMRADA research note in January 1967.[219] But the longer range objective of this overall research area was to relate measurement precision to image quality parameters such as resolution, modulation transfer function, focal length, etc. The connecting link was through the edge gradient generator studies.

Concurrently with the research on visual factors and since this research had shown limitations in existing photogrammetric instruments, a prototype polar coordiante comparator was designed to increase the sensitivity of reading. This instrument, using a laser interferometer and an inductocyn encoder, was designed and fabricated inhouse without the necessity for delicate craftsmanship.

In the area of data reduction and analysis of geodetic satellite data, research activity was implemented in 1964 with the additions of Messrs. Armando Mancini and L. A. Gambino to the Research and Analysis Division staff. Two research notes concerning analysis of geodetic satellite tracking data were published in 1965,[220] [221] and, in November of that year, a research note was published on the satellite angulateration concept,[222] combining optical and electronic ranging observation, as formulated by Mr. Mancini.

In late 1964 and in 1965, work started on the development of several computer programs required to reduce and analyze geodetic satellite tracking data. In December 1964, a contract was awarded to Wolf Research and Development Corporation, Bladensburg, Maryland, for programs for a computation of Combined Gravity Coefficients and Geocentric Datum Shafts (GEOPS) which was completed in March 1966.[223] A research note on GEOPS was published in March 1967.[224] In May 1965, a contract was awarded to International Business Machines Corporation, Cambridge, Massachusetts, for

[219] D. D. O'Connor, RN-21, "Visual Factors Affecting the Precision of Coordinate Measurement in Aerotriangulation," January 1967.

[220] A. Mancini and L. A. Gambino, RN-13, "Results of Space Triangulation Adjustments from Satellite Data," September 1965.

[221] RN-14, "Reduction Procedures for Absolute Direction and Geodetic Azimuths from Optical Observation of Satellites."

[222] A. Mancini, RN-16, "Satellite Angulateration," November 1965. Note: An attempt was made to employ and evaluate the angulateration concept in 1965 employing Baker-Nunn Camera and SECOR observations on the West Coast and Hawaii. The attempt failed because insufficient data was obtained.

[223] "Unified Geodetic Parameter Program (GEOPS)," Volume I, "Mathematical Analysis," Volume II, "Program Description," Final Report, Wolf Development Corporation, March 1966.

[224] A. Mancini, RN-25, "GEOPS," March 1967.

a program for geoid studies from satellite determined gravitational coefficients. This contract was also completed in March 1966.[225] In October 1965, a contract was awarded to Raytheon Company, Autometrics Operation, for a three-dimensional surface triangulation adjustment computer program. This contract was successfully completed in April 1966.[226] During this time, work was completed in-house on a Simultaneous, Angulateration, Triangulation, Trilateration Program (SMATT).

These efforts and additional in-house development of mathematical analysis procedures and programs provided the tools later used in accuracy studies and simulations related to the GEOS-PAGEOS geodetic satellite programs, geoid and gravitational model studies, analyses of SECOR observational data, and studies to develop methods for combining gravity data obtained at the surface of the earth with geopotential and geometric data derived from satellite observations.[227] [228] [229] Preliminary findings on the latter were reported in a paper by Dr. Bjerhammer, "On a Coalescent World Geodetic System, Part I," July 1967. This paper was presented at the International Association of Geodesy meeting, Lucerne, Switzerland, during September and October 1967. Mr. Mancini, while successfully completing 12 months' resident study at Georgetown University in 1967 under the ETL Graduate Study Program, submitted his doctoral dissertation on the development of a gravitational model of the earth from a union of optical, Doppler, and surface gravity data.

Although, by November 1968, all available satellite observations and all surface gravity data had been combined into a single solution to derive the earth's gravitation field model with all zonal and territorial harmonic coefficients up to the degree and order 14, 14, efforts continued in the late 1960's to refine this model and to provide the best possible representation of the external gravity field of the earth and the best possible earth geoid for direct application to the world geodetic system. In 1970, it was planned to make a combined solution using transit data on six satellites and optical data from the Smithsonian Astro-Physical Observatory on five satellites. It was also planned to use 10° by 10° surface gravity data for the integrated solution. As a part of this overall research effort to refine the world geodetic system through combining various types of geodetic data, a study of advanced correlation methods between gravity, geophysics,

[225] "Geoid Representation from Satellite Determined Coefficients," Final Report, IBM, Cambridge, March 1966.

[226] "Modes of Satellite Triangulation Adjustment," Volume I and Volume II, Final Report, Raytheon Corporation, Alexandria, Virginia, April 1966.

[227] RN-22, "A Geometric Simultaneous Multi-Station Determination, With Constraints Using Data From Geodetic Satellites."

[228] A. Mancini, RN-30, "The Earth's Gravitation Field From Observations of Near-Earth Satellites and Terrestrial Gravity Measurements," November 1968.

[229] A. Mancini and Others, RN-31, ETL-211-OD, "Gravitational Models, A Union Solution of Optical and Doppler Satellite Determination," September 1968.

tidal motion, heat flow, and polar motions as they affect the gravitation field of the earth was made in 1969 under contract by Geonautics Operation, Computer Sciences Corporation, Falls Church, Virginia.[230]

Also, in 1969, a new concept of space adjustment was introduced using satellite data with equations of condition. In addition, a new system of geo-grav coordinates and a new concept in defining the astronomic station position were introduced.

The Research Institute Staff continuously supported the Army SECOR program through the late 1960's. Many contributions were made to overcome operational bottlenecks, to improve software and hardware, and to provide for the introduction of advanced concepts. The SECOR reduction program was used in 1968 for simulations of various satellite orbit configurations to determine the orbital accuracy to be expected under certain tracking conditions. Advanced techniques for the reduction of geodetic SECOR observations were developed in 1966 under contract by D. Brown Associates, Eau Gallie, Florida.[231] Analyses of SECOR data were made under contract by DBA Systems, Inc., Lanham, Maryland, in 1968 and 1969.[232] In 1966, in connection with SECOR calibration operations, it was shown that by modeling the bias of a ranging system, ionospheric corrections can be recovered analytically without the need of two-frequency instrumentation. It was also shown that the application of SECOR in a short-arc, dynamic mode would provide better geodetic results than using the system in its geometric trilateration mode. In the hardware area, the in-house program of investigation of solid state UHF amplifiers and satellite transponder investigations resulted in significant contributions to the SECOR System development program of the Surveying and Geodesy Division.

Several other significant accomplishments in the surveying and geodesy area in the late 1960's should be noted here. These are investigations of the shimmer effect on optical observations, an advanced satellite instrumentation study, a study on an ideal world geocentric geodetic system, an investigation of the geodetic application of the eotvos torsion balance, the concept of the application of cesium beam frequency-standards or "atomic clocks" for an electronic measuring device, a new angle measuring concept, and an instrument to correct for atmospheric refraction.

Studies of the shimmer effect on optical observation began in 1965 through analysis of two PC-1000 camera plates of the ECHO satellite. This work was

230 "Gravity Correlation Studies for Determination of the Gravity Field of the Earth," Final Report, Computer Sciences Corporation, Geonautics Operation, January 1970.

231 "Advanced Techniques for the Reduction of Geodetic SECOR Observation," Final Report, D. Brown Associates, July 1966.

232 "Analyses of SECOR Data," Final Report, DBA Systems Inc., Volume I, September 1968, Volume II, October 1969.

continuing in 1969 to 1970 using a 12-inch reflecting cassegrain telescope at the Research Institute Observatory at the North Area Engineer Proving Ground, Fort Belvoir, Virginia. The objective was to determine the magnitude and the frequency of motion of stellar images for short exposure of optical satellites.

The Advanced Satellite Instrumentation Study was performed under contract by Ryan Aeronautics Company, San Diego, California, in the 1967 to 1968 period. The final report was submitted in June 1968.[233]

A contract was awarded to Ohio State University Research Foundation in 1967, to begin in October of that year, for establishing an ideal error budget for each of the components and defining an ideal world geodetic system. The final report was submitted in June 1969.[234]

In 1964, a contract was awarded to the Ohio State University Department of Geodetic Sciences to investigate the geodetic application of the eotvos torsion balance and gravity studies. This work was delayed somewhat by difficulties in procurement of a torsion balance from Yugoslavia but was finally completed in December 1967. Four significant technical reports on this subject were submitted during the investigation.[235 - 238]

The concept of one-way distance measuring using two cesium-beam frequency standards or atomic clocks was under investigation in 1969 and 1970. By this technique, the frequency standards would be used as modulation frequencies for an electronic distance measuring device; the distance would be determined by phase comparison over a one-way path. The efficiency of the system lies in the fact that it is nonsaturable since any number of ground stations can receive at any one time. Possible applications would include ground-to-satellite, ground-to-aircraft, and ground-to-ground measurement.

A prototype instrument was completed in-house in 1969 to investigate a new technique for measuring angles by determining the time it takes a rotating disk to

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233 "Advanced Satellite Tracking Instrumentations Study," Final Report, Ryan Aeronautics Co., San Diego, California, June 1968.

234 "Investigation Related to the Establishment of a World Geodetic System," Final Report, Ohio State University Research Foundation, June 1969.

235 "The Horizontal Gradients of Gravity in Geodesy," January 1964.

236 "The Horizontal Gradients of Gravity in South West Ohio," September 1967.

237 "Interpolation of Deflections from Horizontal Gravity Gradients," December 1967.

238 "Geodetic Control by Means of Astronomic and Torsion Balance Observations and the Gravimetric Reductions of Levelling," December 1967.

sweep out an angle. Investigations indicated that precision manufacturing is not required to achieve high accuracy and that precision greater than 1 second of arc is possible.

In the period 1966 to 1968, a prototype instrument was produced to meet a specific requirement in the Airborne Control System (ABC) to correct for errors caused by atmospheric refraction. The instrument provided for correction of the atmospheric refraction effect on vertical angles by measuring the difference in angle of arrival of light of two different wavelengths. It had the capability of measuring refraction errors of about 2 seconds of arc.

Although the research activity in the mid- to late 1960's was greatest in those areas associated with surveying and geodesy, there were several additional programs in areas associated with map compilation and data acquisition which should be noted.

In the aerial triangulation area, a contract was awarded to the Ohio State University Research Foundations in October 1963 for a comprehensive analysis of photogrammetric model orientation methods.[239] Later, in February 1964, a contract was awarded to the Ohio State University Department of Geodetic Sciences for studies on adjustment of aerial triangulation to be performed at Ohio State by Major Maxwell Jonah in connection with his Doctoral Dissertation.[240] Also, in 1964, a contract was awarded to Cornell University, Ithaca, New York, to study the concept of using triplets as opposed to the use of stereo pairs in analytical aerotriangulation to increase accuracy. The final report on this investigation was submitted by Cornell University in September 1965.[241]

In 1967, the feasibility of in-flight analytical calibration of aerial mapping cameras was established by a flight test over the McClure test range in Ohio as a part of the U.S. Air Force Category II tests of the USQ-28 system. This in-house project required the selection and installation of target lights and ballistic cameras on the McClure range, management of the test operation, and subsequent reduction of the data. It was supported by contract studies by DBA Systems, Inc., which continued into 1969 and included dynamic in-flight testing and evaluation of the SHORAN System as well as advanced methods for the calibration of mapping cameras.[242] [243]

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239 "Investigations Into the Problems of Relative Orientation in Stereo-Aerial Photogrammetry," Final Report, Ohio State University Research Foundation, August 1964.

240 "The Systematic Correction and Weighting of Analogue Aerial Triangulation Observations and Their Use in Strip and Block Adjustments," Final Report, Ohio State University Dept. of Geodetic Sciences, September 1965.

241 "Analytical Aerotriangulation: Triplets and Subblocks Including Use of Auxiliary Data," Cornell University, Department of Surveying, September 1965.

242 "Advanced Methods for the Calibration of Metric Cameras," Final Report, DBA Systems Inc., December 1968.

243 "The Testing and Evaluation of the SHORAN System by Advanced Data Reduction Methods," Final Report, October 1969.

Since the problem of aircraft altitude determination for application in photogrammetric mapping and aerotriangulation processes had always been a major limitation, a contract was awarded to Hughes Aircraft in 1966 to determine a method to replace barometric sensors and isobaric slope techniques to determine the absolute height of an aircraft above datum for altitudes ranging from 500 to 100,000 feet and with operational flight lines of 300 to 400 miles. Accuracies of ±2 feet were a design goal. The final report on this study was submitted in April 1968.[244]

In the color photography area, there was a requirement for means to measure objectively the color of objects in the field as well as the image on color film for quantitative comparison of field object and photo image. This requirement was addressed as early as 1965 by Mr. K. D. Robertson of the Research and Analysis Division staff; two approaches for a portable color-measuring system were advanced.[245] Further work in this area, principally in-house by Mr. Robertson, produced a field instrument in 1969. It consisted of a telescope with a fiber-optic in its focal plane, by which the image of a point whose spectral distribution is required is directed through an adjustable filter so that reflectance at the various wavelengths can be measured.[246] The laboratory instrument is a microscopic version of this and uses many of the parts of the field instrument.

Research on laser holography began as early as 1965 and by 1969 had progressed to the point where a hologram production and measuring system was designed and assembled using a 2-watt argon-ion laser. Two supporting contract efforts were initiated. The objective of the research was to examine the process of recording and measuring the hologram to optimize measurement accuracy and to find the roles for holography in mapping. The in-house work which set the pace in this area up to 1970 was concerned with accuracy of stereoscopic depth measurements on hologram images under varying reconstruction conditions, including various light wavelengths and reduced "speckle," a grainy appearance of holograms which may affect measurements. The supporting contract work which was underway in FY 70 included a study of potential application of holographic techniques to mapping by the Purdue University Research Foundation and a study of the parameters involved in the production of holograms for photogrammetric purposes by the California Institute of Technology.

The fundamental studies of visual metrology in the mid-1960's led to the study of substitutes for film as a recording and information system. More specifically, it led to the study of sensor arrays, which simulated some aspects of the human visual system, for the accurate measurement of position, velocity, area, and object identification.

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244. "Altitude Deviation Study," Final Report, Hughes Aircraft Co., April 1968, CONFIDENTIAL.

245. K. D. Robertson, RN-15, "Two Approaches to a Portable Color-Measuring System," January 1966.

246. K. D. Robertson, ETL-RN-70-1, "Instrumentation for Color Aerial Photography," May 1970.

The sensors would convert optical information into electrical signals convenient for processing, storing, and display.

Theoretical studies in the area were supported in the late 1960's by the University of Virginia under project THEMIS and by a contract study in FY 70.[247] In FY 69 Dr. P. F. Chen, a recent addition to the Research Institute staff, implemented an experimental program. Under this program, a prototype system for linear measurement was completed in FY 70, and an original method was discovered to overcome the accuracy limitation of available commercial arrays by oscillating the input images on the array either mechanically or electronically. The outputs of the array are summed electrically and averaged to give a much better resolution than those which result without image oscillation.

The results of this research program by the end of FY 70 suggested the possibility of the application of array techniques to a wide range of military problems such as: a substitute for film on astronomical cameras enabling real-time measurement of coordinates; application to fine measurement in automatic mapping equipment and surveying instruments; object detection, identification, and tracking; and scanning and digitizing of topographic information from maps and photographs.

Another study in the area of film substitutes for recording and information systems in the late 1960's was a contract study by Illinois University, Department of Civil Engineering, on television display of topographic information.[248]

Research for map reproduction was extremely limited during the 1960's. The Development Division of GIMRADA and subsequently the Development Laboratories of the ETL with Research Institute funding, accomplished what little was done since the Institute had no staff in this area.

The most significant accomplishments in map reproduction research were:

(1) A study of the principles of continuous tone electrophotography[249]

(2) An enhanced photomap study[250]

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247. "The Application of Image Sensing Arrays to Metro... ...tection and Instrumentation," Final Report, University of Virginia, May 1970.

248. "Television Display of Topographic Information," Final Report, University of Illinois, Department of Civil Engineering, November 1970.

249. "Preliminary Study Into the Principles of Continuous Tone Electrophotography," Final Report, American Zinc Lead and Smelting Co., December 1962.

250. "Enhanced Photomap Evaluation Study," Final Report, American Institute for Research, April 1967.

(3) A study of lithographic fountain solutions[251]

(4) A color separation investigation[252]

(5) A map coating concept study[253]

(6) Zinc oxide photo conductivity studies[254]

In the later years of the decade, in-house studies on the properties of zinc oxide were started as were studies on micro-electrostatic analysis and the zinc oxide photo-oxidation process. At the close of the decade, plans were being implemented to emphasize the cartographic aspects of map reproduction since those areas constitute the most serious bottleneck in mapping operations.

A program of basic research in geography was implemented in 1968 to gain deeper knowledge and understanding of the field and to create improved and new theories, concepts, methods, and techniques with the greatest potential for supporting Army capabilities in area analysis and military geography essential to the planning and conduct of military operations. Dr. Roger Leestma was transferred to the Research Institute to head this research area.

The program was set up to provide a more precise understanding of theoretical geography and to examine potential applications of geographic methodology and techniques to military problems in three interconnected areas. The first area was the study of concepts of distribution of geographic phenomena in space and time. This work was to include continuation of a study of geographic spatial patterns and relationships of natural and man-made features of the environment and theories of regionality. The second area of research was to examine geographic methodology, including standards of measurement and scale problems in geographic research. The third area included mathematical and statistical techniques in geography, sampling methods for acquiring data, and mathematical formulas for regions.

In FY 70, three contracts in basic geography were established: The Theory of Quantitative Geography with the University of Iowa; Sampling: a Technique in Acquisition of Geographic Data From Aerial Photographs and Maps with the Regional

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251. "A Study of Lithographic Fountain Solutions," Final Report, Graphic Arts Technical Foundation, September 1967.

252. "Five-Color Separation Investigation," Final Report, General Technologies Corporation, November 1957.

253. "Map Coating Concept Studies," Final Report, General Technologies Corporation, October 1968.

254. "Studies in Zinc Oxide Photoconductivity," Gulf General Atomic, Inc., August 1968.

Research Associates at Ann Arbor, Michigan; and Scale: A Problem in Geographic Research with the University of Denver.

c. **Analytical Photogrammetry.** Both the software and hardware aspects of analytical photogrammetry, specifically analytical aerotriangulation, were areas of major research and development activity in the decade of the 1960's. Software development progressed through a series of steps resulting in the eventual formation of highly sophisticated and advanced techniques and computer programs. In the hardware development area, advanced techniques, which are basic to analytical procedures, were developed for marking and measuring photographic coordinates.

(1) **Analytical Photogrammetry Software Development.** Investigations of analytical aerial triangulation and its application to field use employing a small computer had progressed to the point in the early 1960's where two independent methods had been developed: (1) the Herget method, which had been developed by Cornell University under an ERDL contract[255] and further modified in-house by ERDL and programmed for the IBM 650 computer; and (2) the Zurlinden method developed under a series of personal service contracts with Mr. Robert Zurlinden and coded under contract by the Royal McBee Corporation for the Royal McBee LGP-30 computer.

Paralleling these investigations by ERDL, the U.S. Air Force had also developed the Herget method through contracts with Ohio State University resulting in a group of programs coded for the IBM 650, later recoded for the RECOMP II computer by Autonetics, Inc., under a contract from the Aeronautical Chart and Information Service. Also, the National Research Council of Canada, through the efforts of Mr. G. H. Schut, developed a method of analytical aerial triangulation coded for the IBM 650.

In the early 1960's, in order to arrive at a decision as to the most practicable approach for Army field application, a comprehensive comparative analysis of these four methods was made by GIMRADA.[256] It was concluded that the Schut method developed by the National Research Council of Canada was rapid enough and had sufficient freedom to be the most practicable method tested for field application and that it should be refined for inclusion in an Army Field System of analytical aerial triangulation with small computer. Further refinement of the Schut approach resulted in the development of the Sequential Independent Model Block Analytical Triangulation Program (SIMBAT) in 1966.[257] This program was originally intended to be for the FADAC computer for use in the RACOMS System; however, this idea was abandoned

255. "A Solution of the General Analytical Aerotriangulation Problem," Final Report, Cornell University, May 1958.

256. R. A. Matos, 13-TR, "Analytical Triangulation with Small Computer," May 1963.

257. "Sequential Independent Model Block Analytical Triangulation Program (SIMBAT)," Final Report, Raytheon Company, Autometric Operation, June 1966, Supplement to Final, October 1966.

and SIMBAT was programmed in FORTRAN for the IBM 7094 and the Honeywell 800 computer.

It became clear during initial testing of the Cornell program, coded for the IBM 650 to handle up to six photographs, that the capacity of the program must be enlarged for it to be of any practical value. However, because of the limited speed and storage capacity of the IBM 650, it was found to be impracticable to expand that program further. Since a 100-photograph block was considered a minimum requirement, it was decided to recode the method for a large-scale computer using the basic Cornell University Formulation as revised and reported by Hugh Dodge[258] in 1959.

In the 1960 to 1962 period, the program was coded and refined through a series of contracted efforts resulting in five programs for simultaneous triangulation and adjustment of a strip or a block of aerial photographs. These programs were:

(a) Program 1 (Completed in March 1960): This program was coded by General Kinetics, Inc., for the IBM 704 computer and included the Stiefel method for solving the large system of equations generated by the program.[259]

(b) Program 2 (Completed in April 1961): This program was a revision of Program 1 in which the Stiefel method was replaced by a substitution and elimination method developed and coded for the IBM 704 computer by Mrs. Verna Walters of General Kinetics, Inc.[260]

(c) Program 3 (Completed in June 1962): This program was a revision of Program 1 made by the Massachusetts Institute of Technology.[261] The revision consisted of recoding for the IBM 7090 computer and adding to the program to provide for weighting the input parameters based on the known or predicted accuracy of the data.

(d) Program 4 (Completed in June 1962): This program, also coded by the Massachusetts Institute of Technology, was essentially the same as Program 3 except that the Jordan direct diagonalization method replaced the Stiefel iterative method. Use of the Jordan method greatly speeded up the block solution but limited the solution to a maximum of 26 photographs.

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258. "A Geometrical Foundation for Aerotriangulation," Progress Report 3, U. S. Geological Survey, December 1959.

259. "Digital Computer Program for the Solution of a Photogrammetric Net (Preparation of Maps from Aerial Photographs)," Final Report, General Kinetics, March 1960.

260. "Digital Computer Program for the Solution of a Photogrammetric Net (Preparation of Maps from Aerial Photographs)," Revised Final Report, General Kinetics Inc., April 1961.

261. "Analytical Aerial Triangulation Error Analysis and Application of Comparing Equations to the General Block Triangulation and Adjustment Program," Final Report, Massachusetts Institute of Technology, February 1962.

(e) Program 5 (Completed in December 1962): This program was a revision of Program 4 in which the Jordan method was replaced with a double-precision square root method which would handle up to 28 photographs in a single-block solution. This revision was coded at the National Bureau of Standards in an effort to test the square root method for direct solution of a large system of equations.

As a result of a test and evaluation of these programs,[262] it was concluded that the programs provided a practical tool for obtaining first-order accuracy in photogrammetric application but that additional study was required in the area of error propagation and in developing practical techniques for weighting the observed variables. Also, the technique should he reprogrammed for widespread application on large-scale digital computers.

Further refinement and development of the analytical aerial triangulation technique was accomplished in the 1960's through a series of contracts with the Autometric Operation, Raytheon Company, Alexandria, Virginia.

The first of these contracts, completed in December 1965, resulted in a computer program in FORTRAN IV for operation on the IBM 7090-94. This work included further refinement of compensation for errors in ground and camera positional control data and image coordinates which had been initiated by the Massachusetts Institute of Technology. This program was given the designation "Multiple Station Analytical Triangulation Program" (MUSAT).[263] In June 1968, MUSAT II was completed employing the coplanarity condition equations for the intersection of conjugate rays. In February 1969, MUSAT III was completed using the colliniarity condition which assumes that the object point, image point, and exposure station lie on the same straight line. This version also included blunder elimination, data edit. and the technique called Auto Ray for the rapid solution and inversion of large systems of normal equations. Finally, in November 1970, an expanded MUSAT program designated MUSAT IV was completed.[264] In this program, coded in FORTRAN IV for the IBM 7094 and UNIVAC 1109, the geometrical and physical conditions were enforced simultaneously with known data influencing the solution in accordance with preassigned weights in a massive least-squares solution. Provisions were made for the following: (1) preprocessing the initial photographic observation data to eliminate systematic errors; (2) elimination of blunders; (3) simultaneous block triangulation and adjustment; and (4) comprehensive data edit of image data to remove any remaining less obvious errors. The program also provided for result

[262] Robert A. Matos, TR-34, "Analytical Aerial Triangulation with Large Computer (Analytical Simultaneous Block Technique)," October 1966.

[263] "Multiple Station Analytical Triangulation Programs," Final Report, Raytheon Company, Autometric Operation, December 1965.

[264] Final Report, Volume I, Volume II, Volume III, "MUSAT IV," Raytheon Company, Autometric Operation, November 1970.

analysis, error propagation, and output of absolute or relative position and photographic orientation data. As a minimum, the required input data was estimated exposure station position and orientation, survey ground control, and measured photo coordinates of well-defined image points for which horizontal and vertical positions were to be computed. The program would accept position data input in Geographic, UTM, Geocentric, Local, or Rectangular Coordinate systems. The primary outputs were the orientation matrix for each camera, the camera station and ground positions, and the plate residuals for each measured image point.

These highly sophisticated programs provided a major tool for topographic map production at the U.S. Army Topographic Production Center and also a valuable research tool for further technique refinement and extended photogrammetric applications. In 1970, plans were being made to refine and modify the program further to include functional restraints of baseline measurement and direction and azimuth measurements, and also input-output routines for a wide range of descriptive data for advanced mapping applications.

While the MUSAT program was being developed in the late 1960's for wide application to the solution of analytical triangulation problems, it became necessary to develop another program for use in the RACOMS System. By the mid-1960's, developments in analytical photogrammetry had overtaken the Zurlinden System, and further consideration of this approach for application in RACOMS was abandoned. It was decided to use the BR-133 computer in the RACOMS since this computer was being used for the Automatic Photomapper (APE). The RACOMS System would be required to map areas with little or no ground control. The requirement to provide input to the APE necessitated the development of a special program for this application. The development, also under contract by the Raytheon Company, Autometric Operation, produced the Relative Mapping Triangulation Program (RELMAP).[265] The program was coded in FORTRAN II for the BR-133 and was limited to 25 photographs.

Other software developments and investigations in analytical photogrammetry in the 1960's included the in-house development of the Emergency Target Location Function in 1964,[266] the development of the Fictitious Data Generator by the Raytheon Company, Autometric Operation, in 1965,[267] and the Data Weighting Analysis,[268] also by the Raytheon Company, Autometric Operation, in 1968.

265"Relative Mapping Triangulation Program," Final Report, Volume 1, Volume 2, Volume 3, Volume 4, Raytheon Company, Autometric Operation, June 1969.

266Art T. Blackburn, GIMRADA TR-21, "Emergency Target Location Function," January 1965.

267"Fictitious Data Generator for Analytical Aerotriangulation," Final Report, Raytheon Company, Autometric Operation, September 1965.

268"Data Weighting Analysis," Final Report, Raytheon Company, Autometric Operation, June 1968.

(2) **Analytical Photogrammetry Hardware Development.**

(a) **Zurlinden Equipment.** The fabrication of a prototype set of pass-point measuring instruments as conceived by Mr. Robert Zurlinden for field application of analytical aerial triangulation was completed in the early 1960's. This set included a pass point area-selecting instrument, a pass point selecting and marking instrument, and a pass point measuring instrument. The area-selecting instrument was a precision enlarger in which the coordinator of a reference point in the enlargement of an area in the vicinity of each pass point was precisely determined in the photo coordinate system, and a 10X enlargement of a small segment of the photo around each pass point was made. The point selecting and marking instrument was a special stereoscope to view three stereopairs in the enlargements and accurately mark the selected point on each enlargement. The measuring instrument was a small monocomparator for measuring the X and Y coordinates of the marked points in the small 10X enlarged segment. These added to the reference-point coordinates of the enlarged photo segment gave the coordinate of the point in the coordinate system of the original negative.

As noted previously, other developments in the area of analytical photogrammetry overtook this development. While it was planned in the early 1960's to develop this system for field use, mounted in a van-type truck along with a small electronic computer, it was eventually abandoned for this application, and there was no further development of the system.

(b) **Automatic Point Transfer Instrument.** Since one of the major problem areas in analytical photogrammetric procedures was accurate and rapid marking, measuring, and recording of photo image coordinates, GIMRADA, in the early 1960's, embarked on a program to automate this operation and thus increase the speed of the operation and improve the precision and accuracy over the manual stereo and mono marking and measuring approaches then available.

In 1964, the Link Group of Singer, Inc., at Binghamton, New York, produced a prototype instrument which was called the Automatic Point Marking, Measuring, and Recording Instrument (APMMRI)(Fig. 99).[269] This instrument incorporated in one assembly precision tables with automatic readout to measure photo points, a marking system to mark selected points, and an electronic scanning and correlation system to select conjugate image points automatically. It was the first of its kind ever produced and demonstrated the feasibility of electronic image matching. It also demonstrated the advantage of doing all operations on one instrument instead of using separate

[269] "Automatic Point Marking, Measuring, and Recording Instrument," Final Report, General Precision, Inc., Link Division, December 1964.

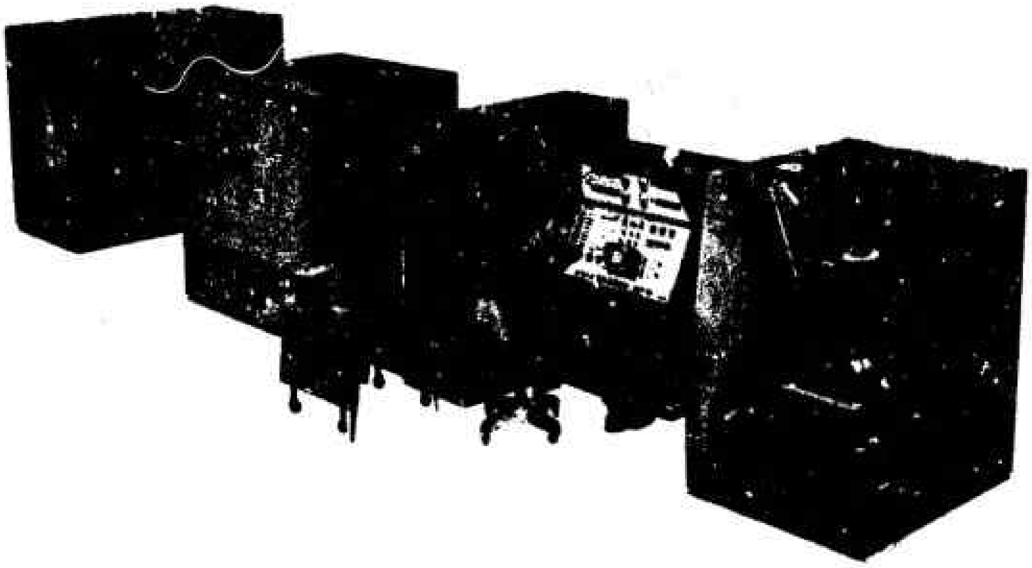

Fig. 99. Automatic Point Marking, Measuring, and Recording Instrument (APMMRI).

marking and measuring instruments as in the Zurlinden System, since it reduced blunders and improved speed of operation.

The APMMRI was limited in that it could only accept nominally equal scale vertical photographs as input. Therefore, in 1965 work started on the automatic point transfer instrument (APTI), a sophisticated version of the APMMRI (Fig. 100), to provide universal capabilities for all types of photography with variations in scale, tilt, and format including panoramic photography. This instrument was also built by the Link Group of Singer, Inc., and was delivered to GIMRADA in 1967.[270] It was basically a three-stage electronic stereocomparator with a marking capability. The major characteristics of the instrument were highly precise air-bearing tables, independent variable magnification, heated die marking system, and electronic scanning and correlation. It had automatic readout on the typewriter and card punch and read-in system to position the tables to predetermined coordinates.

This instrument was installed at ETL in a specially designed white room with controlled environmental conditions; extensive engineering tests were conducted beginning early in 1968 and continuing to the fall of 1970.[271] During this period, some special tasks were performed with the instrument and an operation and

[270] "Automatic Point Transfer Instrument," Final Report, General Precision, Inc., February 1968.

[271] Maurits Roos, "Test Results of the Automatic Point Transfer Instrument," presented at Annual ASP-ACSM Convention, Washington, D. C., March 1971.

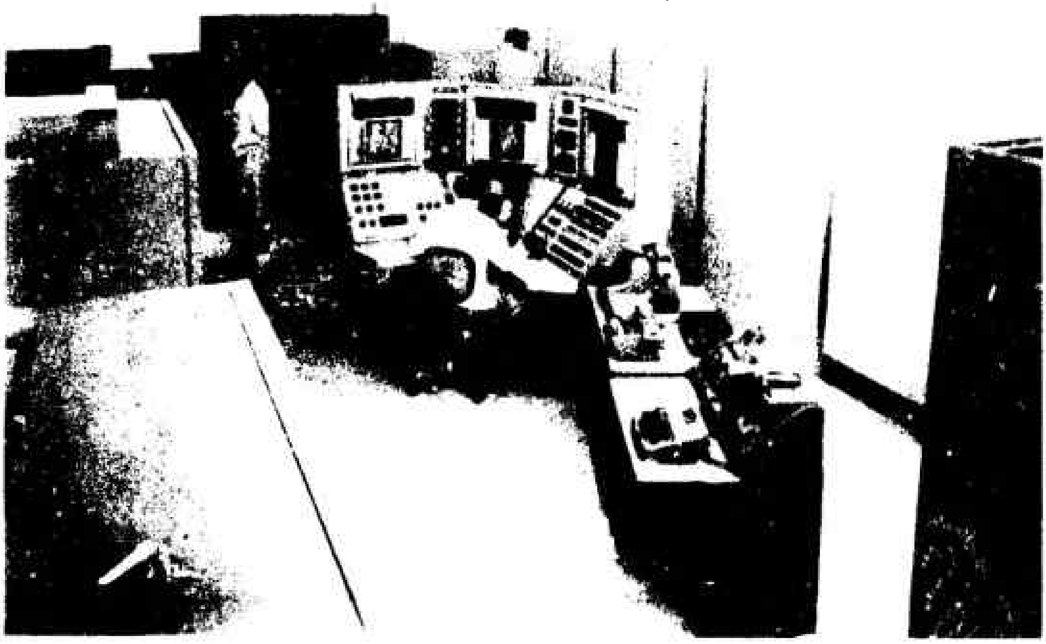

Fig. 100. Automatic Point Transfer Instrument (APTI).

maintenance familiarization program was conducted for U.S. Army Topographic Command Personnel to aid in preparing the transition of the instrument into production at TOPOCOM – scheduled for the beginning of 1971.

This equipment is one of the most complex items developed by ETL in terms of complex electronic logic and mechanical design while maintaining high precision, yet downtime experienced during engineer tests was within acceptable limits. The instrument should provide a valuable tool for analytical triangulation and other applications when the usual operating problems associated with the introduction of a new and complex item into production operations are solved.

(c) **Variscale Stereo Point Marking Instrument.** While exploratory investigations for the automation of the process point marking, measuring, and recording of photo pass points had been implemented in the early 1960's, it was apparent that this was a long-term development. In 1963, an urgent requirement developed for a variable stereo point marking instrument in connection with the development of the Universal Photogrammetric Data Reduction and Mapping System (UPDRAMS) at the Army Map Service. Satisfaction of this requirement could not be deferred pending the automatic equipment development. An accurate marking instrument which could place a variety

of high quality marks on one or two photographs which may have large differences in scale and format was required.

To meet this requirement, detailed technical characteristics were prepared in 1963. In April 1964, a contract was awarded to Bausch and Lomb, Inc., Rochester, New York, to design, develop, and fabricate two instruments (Fig. 101).[272] The first of these was completed and delivered to Army Map Service in September 1965, and the second was delivered to GIMRADA in March 1966. After engineer tests at GIMRADA, the second instrument was transferred to Army Map Service in March 1967.

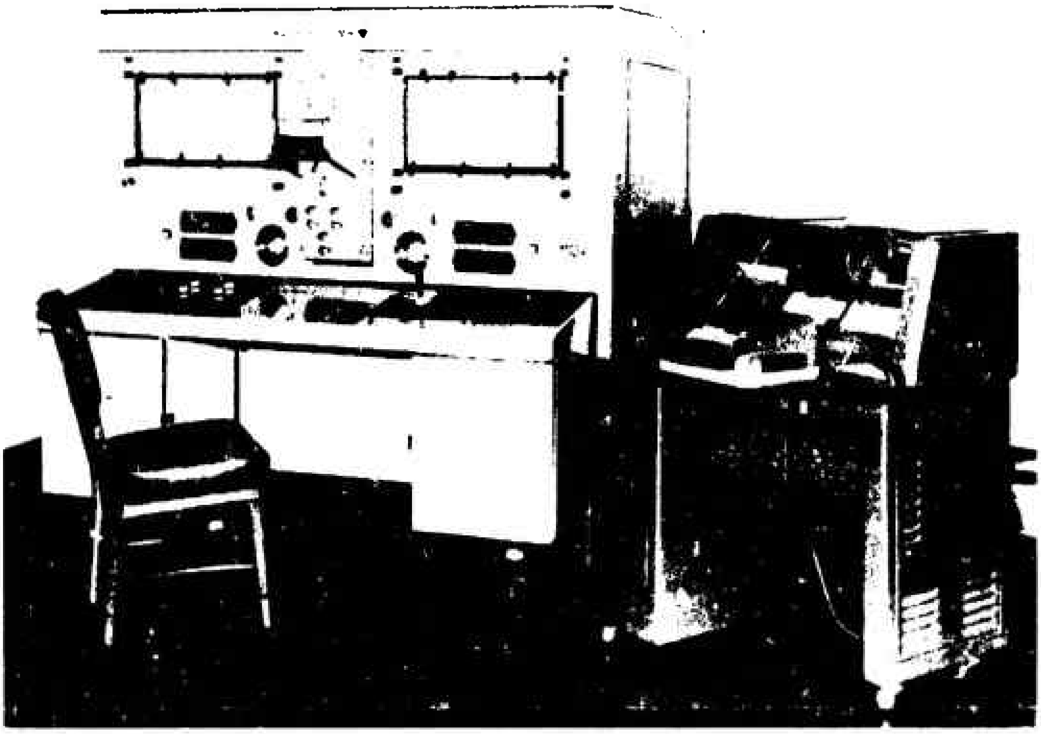

Fig. 101. Variscale Stereo Point Marking Instrument.

This instrument included two photo carriages with vacuum-type plate and film holders for sizes up to 10 inches by 19 inches, two independent optical trains which had continuously variable magnification from 2X to 32X, and a choice of reticles and two photo displays with pointers to hold reference prints of the photos being marked. The tables were motor driven by joystick control and had a

272. "Development of Variscale Stereo Point Marking Instrument," Final Report, Bausch and Lomb, Inc., September 1966.

coarse readout displayed on the console with nixie tuhes. A card punch unit was provided with the instrument to record point identification and coordinate data. The marking of the photo emulsion was by a capacitor-discharge heated die with a choice of several sizes and shapes of marks. This was specially developed for this instrument after extensive investigation of other marking approaches which were not satisfactory.

Engineer tests[273] indicated a precision and accuracy of better than 2 micrometers standard deviation. High quality marks were produced by the heated die technique.

While no further procurement of this particular item was made to meet production requirements, it did provide valuable information in the development of technical characteristics for subsequent instrument procurement by the Production Center, TOPOCOM.

(d) **Semiautomatic Coordinate Reader.** Another development of photo-coordinate measuring equipment, initiated in the early 1960's, was the Semiautomatic Coordinate Reader (SACR) (Fig. 102). This instrument was to provide a mean for measuring marked photo points, reseau points, and star plates at relatively high rates of speed and to include a means for automatic centering on these photo images.

A purchase description for this item was developed in August 1962. As a result of contract negotiations in late 1962 and early 1963, a fixed-price contract to design and produce one instrument was awarded to Nuclear Research Instruments, Berkeley, California, a Division of Houston Fearless Corporation, in February 1963. Almost exactly 1 year later, this contract was modified to include a card punch and control unit, a format viewer, and a government-furnished computer – the SDS 910 – for programmed control of sequential, image-coordinate measurement. In September 1964 before the first model had been completed, a contract was negotiated with Nuclear Research Instruments for a second instrument, and in April 1965 this contract was modified to add a third instrument to meet urgent requirements of the Army Map Service.

This development was fraught with exasperating delays due to varied mechanical and electronic problems, and it was not until May 1966 that the first of the three units under contract, SACR 1, was delivered. This unit was delivered directly to the Army Map Service where it was installed and adjusted by the contractor. Acceptance testing was completed in June 1966; however, it was necessary to relax the automatic pull-in radius and size of target requirements of the original specifications.

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[273] M. Roos, ETL-39-TR, "Variscale Stereo Point Marking Instrument," April 1968.

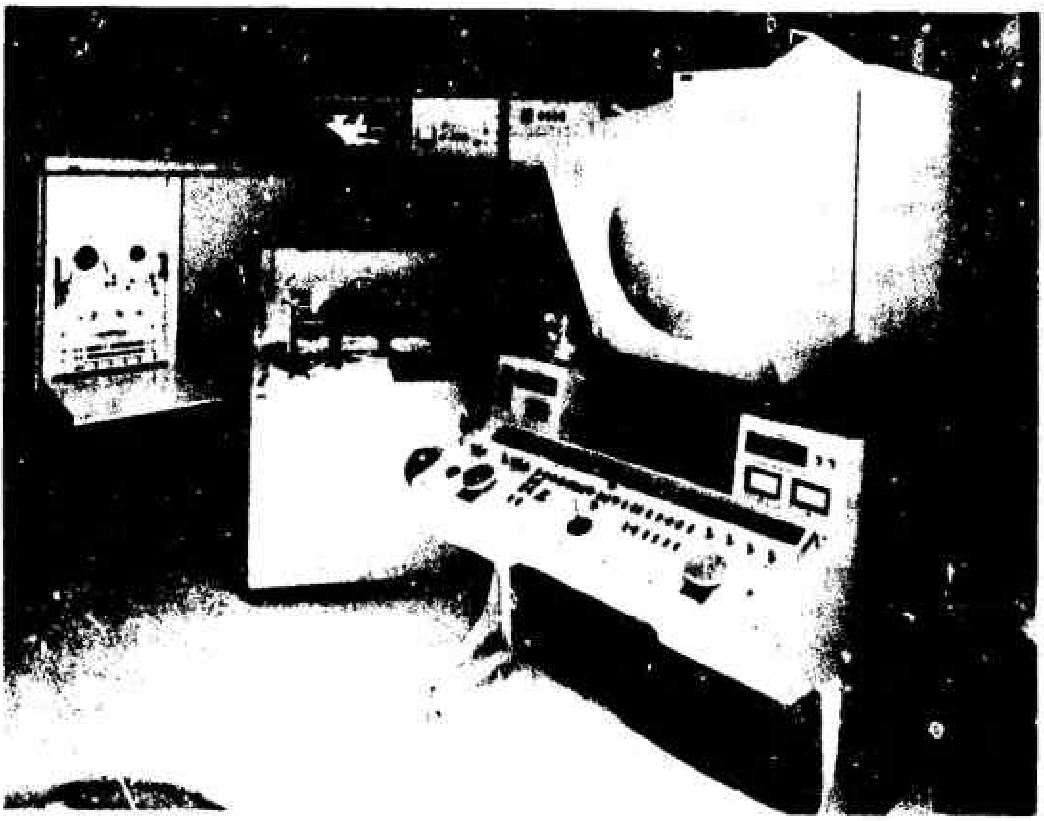

Fig. 102. Semi-Automatic Coordinate Reader (SACR).

The second unit, SACR II, was delivered to GIMRADA in August 1966. After many problems with the computer, the air compressor for operation of air bearings of the instrument, etc., acceptance tests were completed in October 1966. SACR III was delivered to the Army Map Service in November 1966, and acceptance testing was completed by December 1966.

While SACR I and SACR III were placed in production at the Army Map Service, the engineer test of SACR II by GIMRADA was plagued with a series of electronic and mechanical failures including problems with the air conditioning system of the portable white room installed for the SACR. The instrument deteriorated to the point where it was concluded in the fall of 1968 that a major overhaul by Nuclear Research Instruments would be necessary to put it in suitable operating condition to provide meaningful performance data. This major overhaul could only be justified if the instrument would eventually be needed by the Production Center, TOPOCOM. Since it was determined that the instrument was not needed there, the overhaul was not made. Rather, engineer testing to develop performance data for the SACR was performed with

SACR III at the Production Center, and SACR II was declared excess. However, these tests were not performed until mid-1970.

While this development was plagued with many problems, the equipment did eventually perform in the manner originally intended and with a sufficient degree of accuracy and reliability.

d. Map Compilation Systems. Building on the technology developed during the 1950's and the concurrent advancement of technology in the digital computer field, the work on map compilation systems in the 1960's proceeded along several related and parallel courses to meet a rather wide variety of requirements. Basically, it can be said that these requirements called for greater precision and greater speed in the map compilation process and the utilization of a wide variety of sensor information, including radar, to produce useful topographic products.

Developments through the 1950's and into the 1960's can be characterized as being strictly toward manually operated analogue instruments, although research on automation was started in the early 1950's. The first attempts to automate the compilation process were through modification of conventional analogue stereoplotters by adding electronic correlation devices whereby the registration or misregistration of homologous images on overlapping stereoscopic photographs could be precisely measured and control the plotter operation automatically. Since these approaches were rather limited to a specific range of camera focal length, camera format, camera lens distortion, etc., development of the computer-controlled instrument approach was the next logical step to handle the wide variety of sensor input information. Through the computer-controlled instrument approach, the mathematical function describing the relationships between the photo coordinates and ground coordinates is solved in a continuous operation by the digital computer which also controls the scanning of both the input imagery and the output. These mathematical functions may include the parameters of film shrinkage, earth curvature, lens distortion, atmospheric refraction, and other systematic distortions and permit unlimited flexibility in terms of focal length, type of camera, etc. The development of computer controlled approach employing electronic correlation of imagery was one of the major accomplishments of the 1960's.

Paralleling the development of the computer-controlled instrument approach, considerable work was done on the all-digital approach to automation of map compilation. Conjugate images are located by digital correlation; that is, statistical matching of spot densities, by a programmed digital computer which also solves the mathematical function expressing the relationship between photo coordinates and ground coordinates as in the digital controlled plotter. This approach could use a general purpose computer with appropriate input equipment to convert the input photographic images, spot by spot, into digital values representing gray scale levels and an

appropriate output device to print out the photo imagery and contours from the computer output after analysis and manipulation. This could be the approach that will be followed in the next generation of automation map compilation equipment.

While automation, as exemplified by the Universal Automatic Map Compilation Equipment (UNAMACE) and the APE, was a highly significant accomplishment of the 1960's, there were other major programs in the map compilation area in this time period. These included a series of unique developments in the radar data reduction area, continuing developments in the analogue stereoplotter area to accommodate special camera configuration, a major effort to proivde means for accommodating reconnaissance photography in a base plant operation, and most significantly the development of RACOMS. The RACOMS development brought together the latest technology in the photogrammetric compilation, cartographic, and map reproduction areas to provide a totally integrated map production facility.

(1) **Ultra Wide Angle Mapping Equipment.** As interest in the development and application of the convergent 6-inch focal length, 9- by 9-inch, wide-angle photography and applicable compilation equipment waned in the late 1950's, interest revived in the potential of ultra-wide-angle systems for military mapping when Wild Heerbrugg Ltd., Heerb, Switzerland, announced the development of an ultra-wide-angle camera, the RC-9, and also the Wild A-9 autograph and the U3-A diapositive printer. This system not only provided the inherent advantage of the large base-to-height ratio as in the convergent camera approach but also provided wider coverage per flight strip with near-vertical photography; thus, there were fewer models to handle with the simplification of near-vertical photography. Interest in an ultra-wide-angle system by the Corps of Engineers dates to World War II days when it was indicated that an ultra-wide-angle system would be a valuable approach to military mapping. Efforts were made to develop an ultra-wide-angle camera lens in the World War II period through a program set up in the National Research Council, but the program was unsuccessful and the development was abandoned in the mid-1940's.

Both the Army Map Service and the Topographic Engineering Department, ERDL, implemented experimental investigations of ultra-wide-angle mapping in the late 1950's. The Topographic Engineering Department, ERDL, procured the Wild equipment for test, and the Army Map Service procured a set of ultra-wide-angle multiplex equipment from Zeiss-Jena of East Germany for test. Concurrently, the Air Force procured the Wild RC-9 Automatic Film Camera.

As a result of these experiments, it was concluded that an ultra-wide-angle mapping system was practical for military mapping: it provided a ground coverage advantage of about double that of the then standard mapping systems, 6-inch focal length and 9- by 9-inch format. The advantage in ground coverage would provide

faster and more economical mapping through reduction in flying time, reduction in field control, and more efficient stereo plotting.[274]

Following these tests, the development of an ultra-wide-angle stereoplotter was initiated. A development contract was awarded to the Belfort Instrument Company, Baltimore, Maryland, in 1962 for a projection-type stereoplotter. A separate contract was awarded to Fairchild Camera and Instrument Corporation for six ultra-wide-angle projection lenses to be government-furnished equipment for the stereoplotter. Originally, it was planned to use these lenses to modify both the high precision military plotter and the Army Map Service M-2 plotter to accommodate ultra-wide-angle photography. Concurrently, the Air Force modified two KC-1 cameras by mounting 88-mm focal length Wild Super-Aviogon Lenses of the Wild RC-9 camera in KC-1 type camera bodies thus providing a camera designated the KC-3 which produced 120° ultra-wide-angle coverage along the diagonals on a 9- by 9-inch format. At the request of the Corps of Engineers, the U.S. Army Signal Research and Development Laboratories initiated the development of an ultra-wide-angle precision mapping camera.

The Curtis Division of Fairchild Camera and Instrument Company encountered considerable difficulty in producing suitable ultra-wide-angle projection lenses, and it was not until mid-1964 that acceptable lenses were finally produced. In the meantime, the plotter development had been delayed, and it was not until September 1965 that final acceptance of the plotter was completed and contract termination was begun (Fig. 103).

Further work on the ultra-wide-angle plotter was suspended on acceptance of the prototype plotter. As the result of an ultra-wide-angle mapping review directed by OCE, it was noted that while there were many occasions where the use of ultra-wide-angle photography would be advantageous, there was no ultra-wide-angle camera produced in the United States. In reply to OCE on this study GIMRADA recommended that the Air Force be requested to develop a suitable camera.

(2) **Interim High Altitude Mapping System.** Another mapping system development of the early 1960's was the Interim High Altitude Mapping System, generally known as the HALCON Mapping System. This development was actually implemented in 1958 as the result of a study on the problem of producing standard topographic maps from photography at altitudes up to 100,000 feet. This study proposed a convergent, 18-inch focal length, 9-inch by 9-inch format camera with an optical projection plotter to match. It was estimated that such a system could produce 20-foot

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[274] Q. C. DeAngelis, GIMRADA 6-TR, "Tests and Evaluation of Ultra-Wide-Angle Mapping Photography," June 1962.

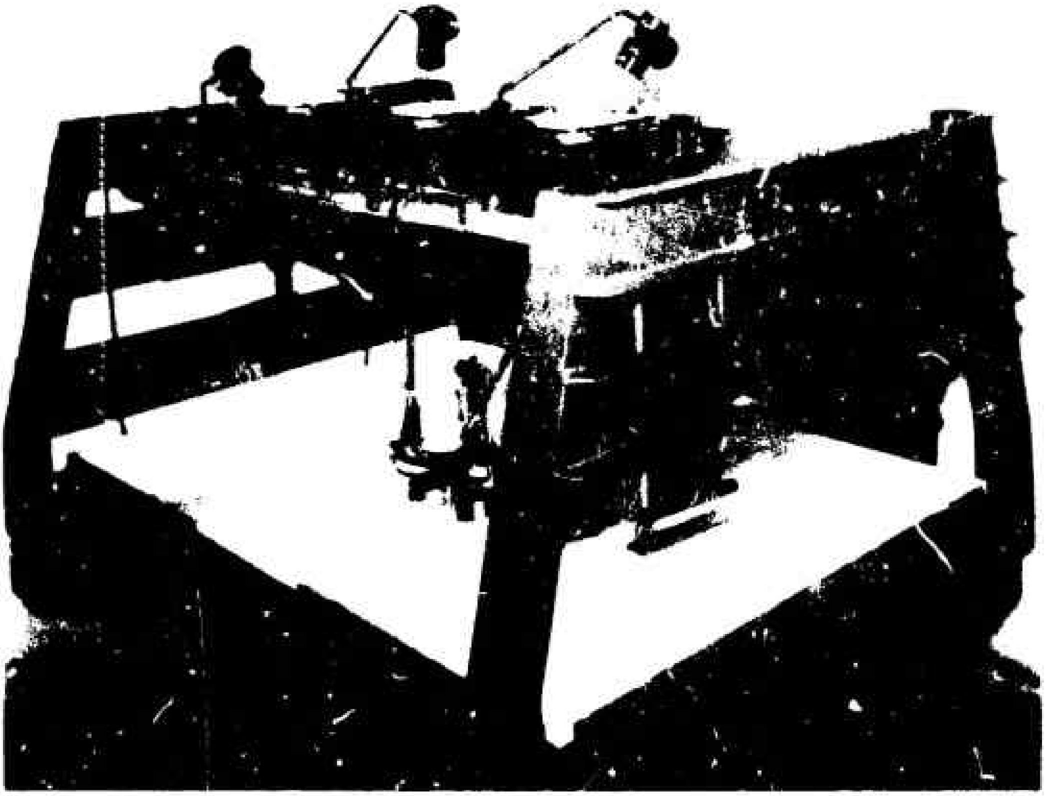

Fig. 103. Ultra-Wide-Angle Stereoplotter.

contours approaching national map accuracy standards from 100,000-foot altitude photography.[275]

To test the feasibility of such a system, it was proposed that a trial be made with 12-inch reconnaissance-type cameras and a Kelsh-type plotter—both modified to meet the requirements of the system. Two K-17, 12-inch focal length aerial cameras were obtained. A contract was awarded to the Kargyl Company, Inc., San Antonio, Texas, in June 1958 to modify the cameras to meet established standards for precision aerial mapping cameras, to fabricate a twin camera mount to hold the two cameras in a 50° convergent configuration, and to obtain 12-inch focal length and simultaneous 6-inch focal length aerial photography of a controlled area.

Concurrently with the camera modification, a companion projection type stereoplotter was developed under contract with the Fairchild Aerial Surveys,

[275] J. W. Halbrook, ERDL 1518-TR, "A Proposed Stereophotogrammetric System for Topographic Mapping from Photography Taken at Altitudes up to 100,000 Feet," March 1958.

Inc., Pasadena, California, also awarded in June 1958, and subsequently subcontracted to Boller and Chiners, Inc., South Pasadena, California. This instrument, called the HALCON plotter, was delivered to ERDL in December 1959 (Fig. 104). This plotter was of the anaglyphic projection type capable of accepting distortion-free, 12-inch focal length and distortion-free or metrogon 6-inch focal length photography. Three matched pairs of cones and projection lenses were provided; one for projection of 12-inch focal length photography at 5-diameter magnification; one for projection of 6-inch focal length photography at 5-diameter magnification; and one for the projection of 6-inch focal length photography at a 10-diameter magnification. The projector supporting frame was adjustable in height as required for the various configurations, and provision was made for vertical or convergent, 12-inch or 6-inch photography and also transverse 6-inch focal length photography to a maximum oblique angle of 60°.

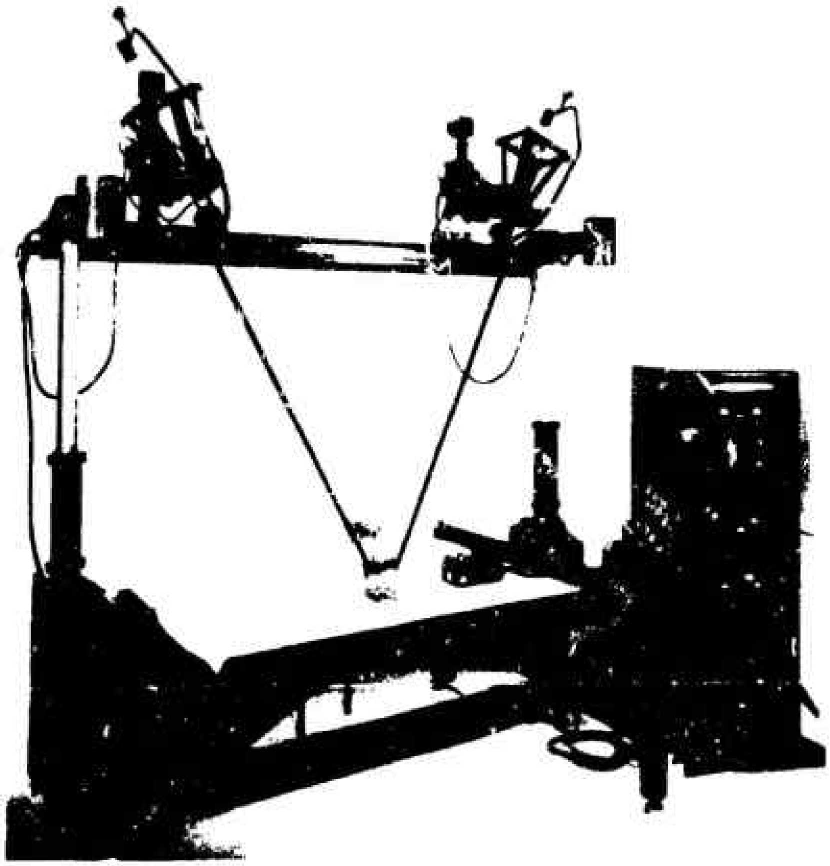

Fig. 104. Interim HALCON Stereoplotter, 12-inch focal length.

Tests with this equipment in 1960 and 1961 confirmed that the estimated capabilities of the proposed system as set forth in ERDL Report 1518-TR

were valid, and the HALCON systems could provide a capability for increased contouring accuracy from high altitude photography.

This HALCON equipment proved to be very useful in solving an Advanced Research Projects Agency (ARPA) problem of measuring the subsidence at underground nuclear test sites. GIMRADA participated in a series of these events in the 1962 to 1964 period using pre- and post-shot photography of the paneled test areas. Photography was obtained by the U.S. Air Force, 1370th Photo Reconnaissance Wing, and the photogrammetric reduction was done at Fort Belvoir.

Early in 1963, it was decided to explore further the application of the convergent, long-focal-length camera system approach to mapping from extremely high altitudes through experimentation with 12-inch focal length photography on a 9-inch by 18-inch format. In June 1963, a contract was awarded to the Aero Service Corporation, Philadelphia, Pennsylvania, to: (1) modify a K-38 reconnaissance camera by equipping it with a high-quality, 12-inch focal length, wide-angle lens and making other changes to meet cartographic camera requirements, (2) design and fabricate new projectors for the HALCON plotter to accommodate 9-inch by 18-inch photography, and (3) design and construct a one-to-one projection printer with an aspheric distortion corrector plate for making diapositives for the new HALCON plotter (Fig. 105).

Fig. 105. Diapositive Correction Printer for interim HALCON mapping system.

The modified K-38 camera was delivered to GIMRADA in June 1964 but had to be returned to the contractor in February 1965 to correct deficiencies found in flight testing. It was returned to GIMRADA in July 1965 but again had to be returned to correct malfunctioning fiducial mark illumination. All items of the contract were finally completed and delivered to GIMRADA by October 1965.

With the delivery and acceptance of the updated HALCON equipment, this development program was terminated since there was no companion mapping camera of U.S. manufacture for the system. By this time, it was also apparent that the UNAMACE would be applicable for the reduction of the type of photography for which this system was designed. The equipment, however, was useful as a laboratory tool. In 1968, the plotter was loaned to Raytheon Corporation, Autometric Operation, for use on a special research project for the Advanced Research Projects Agency, Department of Defense, and later in 1970 it was transferred to the U.S. Geological Survey for use as a research tool.

(3) Automatic **Mosaicking** System. The concept of an automatic mosaicking system originated in 1959 in connection with studies of the problems of target location for Army surface-to-surface missiles. In these studies, it was determined that a gridded photo mosaic would be useful for target location if it could be produced at a greater speed than the manual cut and paste method of mosaic assembly. Further, developments in airborne navigation and aircraft positioning systems indicated that position and attitude information could be recorded simultaneously with the aerial photography, thus providing the control which could be used as input to automatic equipment for photo rectification and positioning of the photo images on a grid system.

In April 1959, a contract for the design and fabrication of an automatic mosaicker was awarded to the Union Instrument Company, Plainfield, New Jersey. Part of the equipment was delivered to GIMRADA in March 1961, but the balance of the contract was not completed until March 1962. The principal requirements were that vertical aerial photography, 6-inch focal length, taken at altitudes from 10,000 to 50,000 feet, with residual tilts up to 10°, be mosaicked into a controlled gridded photo map at 100,000 scale with a physical dimension of 24 by 24 inches (Fig. 106).

While the original concept had envisioned a single unit consisting basically of a rectifying projector, an easel, a supporting structure, and the necessary photographic processing equipment, it was found in the early stages of the contract that this was not feasible within the specified range of magnification and tilt. The system produced, therefore, was a two-stage system, with two basic pieces of equipment. In the first stage, the photos were rectified automatically at a small reduction in scale; and, in the second stage, the final scale adjustment and positioning of the control grid

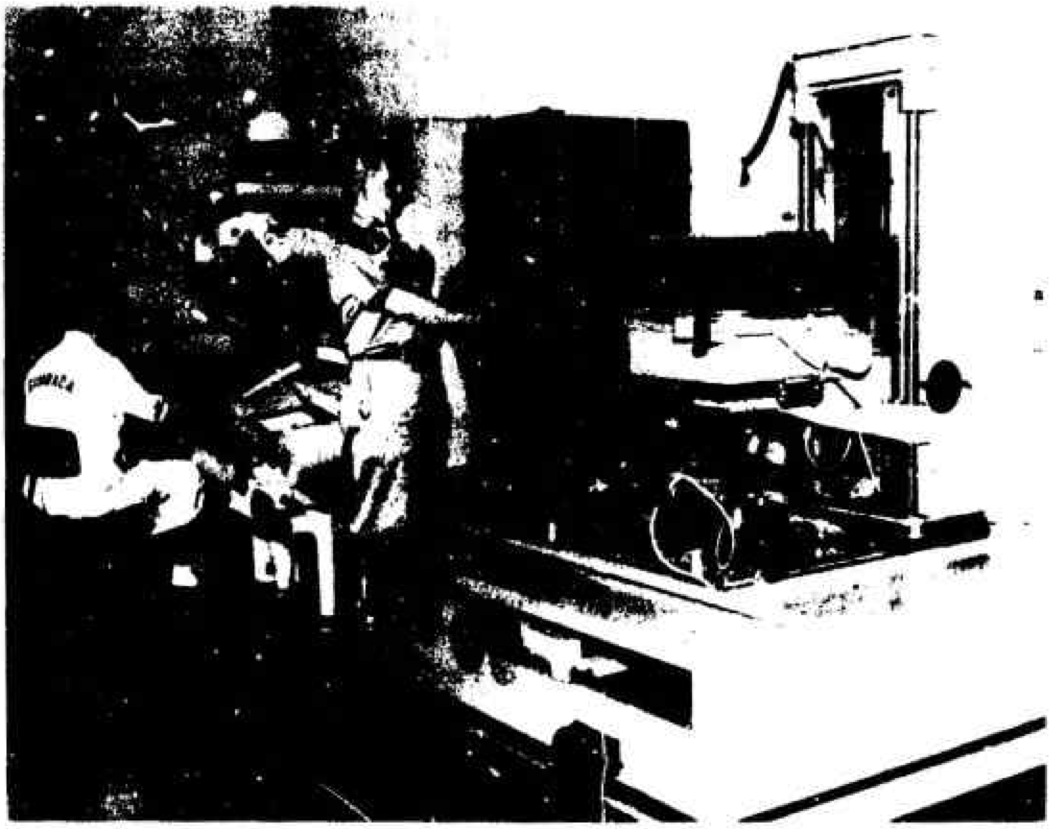

Fig. 106. Automatic Mosaicking System.

was accomplished. The autofocusing rectifier unit was actually a modified Zeiss automatic focusing rectifier with controls added for automatic operations.

Engineering and operational tests of this equipment were conducted in 1962 and 1963.[276] It was concluded that the system was capable of producing controlled gridded mosaics and that the time required for the operation in producing a 1:100,000 scale mosaic was approximately one-seventh of that required for completely normal operation. The accuracy of the mosaic produced in the test was satisfactory; however, the accuracy was dependent on the nature of the orientation data available. In the test compilation, these data were determined from stereoscopic model setups in a Wild A-7 autograph.

This development was never pursued beyond the prototype stage because developments in orthophotomap production equipment overtook this development and it was decided eventually to equip the RACOMS with the automatic photomapping equipment.

[276] Abraham Anson, GIMRADA 17-TR, "Prototype Automatic Mosaicking System," November 1963.

(4) **Automatic Map Compilation.** At the beginning of the 1960's, developments in the automatic map compilation area had progressed to the point where ERDL had successfully demonstrated the feasibility of an automatic stereomapping system based on mechanical scanning utilizing a Nipkow disc. The feasibility of electronic image scanning by a flying spot scanner had been demonstrated in an automation of the contouring function of the Kelsh plotter by Gilbert L. Hobrough of the Photographic Survey Corporation of Canada. Paul Rosenberg Associates, under an ERDL contract, had breadboarded a piece of hardware which was based upon integrating flying spot scanners and electronic correlation with a digital computer for computation and control.

While GIMRADA continued tests and evaluations of the stereomat approach of adapting projection-type stereoplotters to automation in the early 1960's,[277] it was realized that these approaches had fundamental limitations in terms of universal application. Therefore, in 1960, a contract was negotiated with Ramo-Wooldridge Corporation, Canoga Park, California, to develop the Automatic Map Compilation System. This system was designed from the start as a completely automatic instrument for high-speed compilation in a computer-controlled operation with electronic scanning and correlation along the lines suggested and demonstrated by Paul Rosenberg Associates.

The prototype equipment was delivered to GIMRADA in December 1963. The principal elements of this equipment were a PB 250 digital computer, a single scanning and print table, and electronic correlation circuitry. The scanning and print table provided for scanning the diapositive pair with two CRTs and for the printout of the orthophotograph and the line drop contours by two additional CRTs. These four units were assembled on one table.[278] [279] [280]

This development proved to be highly successful as a prototype demonstration of a computer-controlled system (Fig. 107). Therefore, in February 1963, even before the prototype Automatic Map Compilation System was delivered to GIMRADA, a contract was awarded to Ramo-Wooldridge Corporation (later Bunker-Ramo Corporation) for the Universal Automatic Map Compilation Equipment (UNAMACE). This equipment included a number of advanced features designed to enhance its utility in a production environment and increase the speed and accuracy of its operation as compared to the prototype Automatic Map Compilation System. It

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[277] Kent T. Yoritomo, GIMRADA 4-TR, "Prototype Stereomat System," March 1962.

[278] "Automatic Map Compilation System," Final Report, Phase I, Thompson Ramo Wooldridge, Inc., January 1962.

[279] "Automatic Map Compilation System," Final Report, Phase II, Thompson Ramo Wooldridge, Inc., May 1962.

[280] "Improvement Program Automatic Map Compilation System," Final Report, TRW Computers Co., January 1964.

was designed to accept universal inputs, including a large range of camera focal lengths and tilts, 9- by 18-inch input diapositives, and all known photographic camera configurations including convergent frame and panoramic pairs.[281]

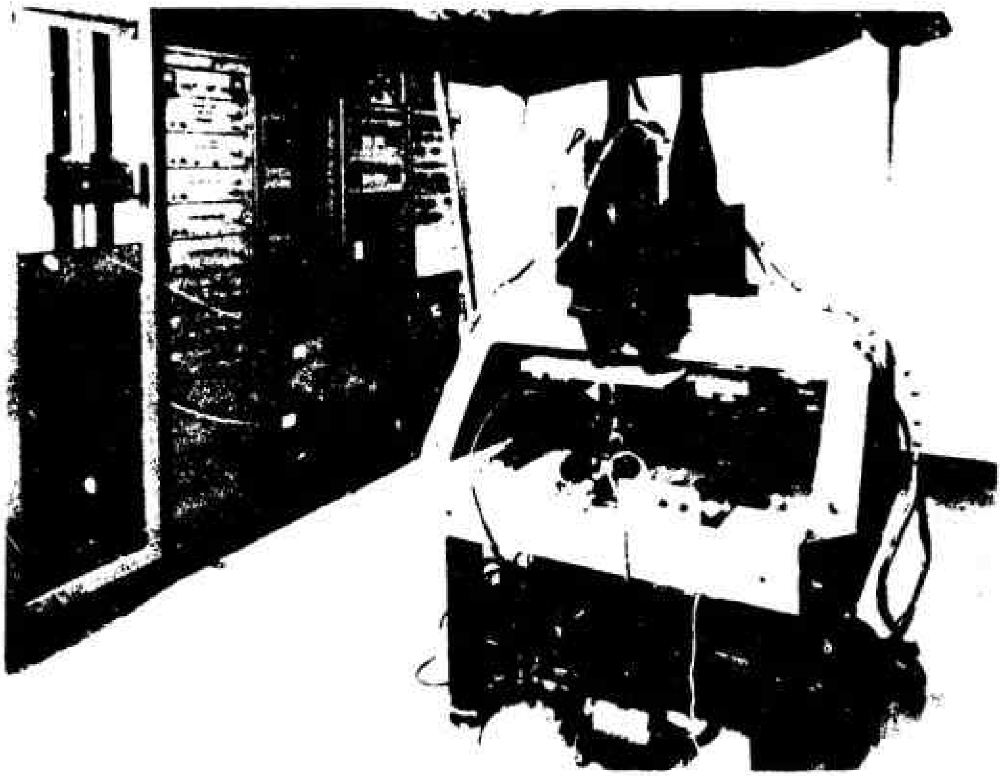

Fig. 107. Prototype Automatic Map Compilation System.

The major elements of the UNAMACE were four identical 9- by 18-inch precision comparator tables for scanning the input and printing the output, a TRW-133 digital computer with associated input-output equipment to control the automatic operation, a control console for monitoring and manual control of the operation, and a magnetic tape recorder and its associated controller (Fig. 108).

Two UNAMACE systems were produced under the Bunker-Ramo contract and these were delivered, one to the Army Map Service and the other to GIMRADA, in September 1965. Subsequently, two more UNAMACEs were procured for the Army Map Service. In the period from January 1966 to March 1969, the equipment went through a shakedown in which considerable computer reprogramming, additional programming, and minor equipment modifications were necessary; and complete

281. "Universal Automatic Map Compilation Equipment," Final Report, Bunker Ramo Corporation, October 1965.

Fig. 108. Universal Automatic Map Compilation Equipment (UNAMACE).

engineer design test and evaluation were conducted. In March 1969, the UNAMACE at ETL was relocated to the Production Center, TOPOCOM.

The engineer design tests[282] demonstrated the capability of the equipment to produce single-model, 7½-minute and 15-minute quadrangle contoured orthophotomaps with contouring accuracy ranging from C-factor values of 1150 to 2300 and compilation speeds of 1 hour for a 4.5- by 9-inch single model at input-output ratio of 1:1, 5¼ hours for a 7½-minute quadrangle at 1:1 input-output ratio, and 4¼ hours for a 15-minute quadrangle at a 2:1 input-output ratio (1:100,000 scale). This development produced the first operationally feasible automatic mapping system.

While development of the UNAMACE was in progress in the mid-1960's, a field version of this equipment called the Automatic Photomapper Equipment (APE) was developed under GIMRADA contract to the Bunker-Ramo Corporation and was delivered to GIMRADA in November 1966 (Fig. 109). It was a ruggedized, van-mounted mapping system capable of producing high-quality orthophotos and contours to a desired scale for rapid mapping operations for field topographic units. This unit was incorporated in the experimental Rapid Combat Mapping System (RACOMS) (Fig. 110). It was designed to accept similar input photography to the UNAMACE up to 10 by 10 inches in size.

[282] Edward F. Burzynski and George Ferrence, ETL 51-TR, "Universal Automatic Map Compilation Equipment," December 1969.

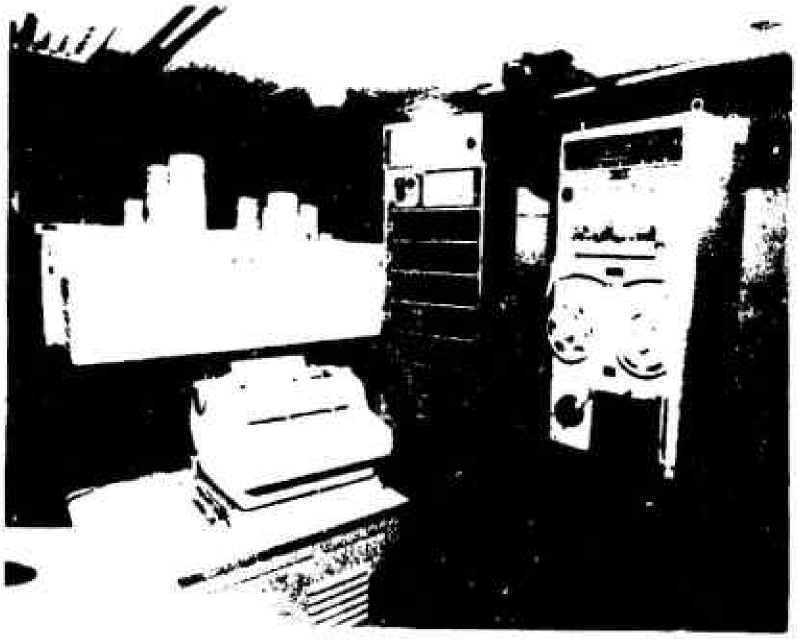

Fig. 109. Automatic Photomapper: Input/Output Printer, Scanning/ Printing Table, Computer, Controller.

Fig. 110. Automatic Photomapper: Controller, Electronic Racks, Control Console, Input/Output Printer.

Another development of the late 1960's associated with the UNAMACE development was the High Resolution Orthophoto Output Table (HIROOT) under contract to Singer-General Precision, Link Division, Sunnyvale, California.[283] The equipment was designed to provide orthophoto output from the UNAMACE System up to 24 by 30 inches in size and with 100-line per millimeter resolution.

As the development of the UNAMACE was coming to a successful conclusion in the late 1960's, in-house work started on a follow-on Advanced Automatic Compilation System (AACS). This system would use a calibrated, all-electronic scanning system in lieu of the mechanical X and Y tables to provide greater speed and flexibility of operation, reduction in size and weight in comparison to the UNAMACE, and probably a reduction in cost. The output will be a magnetic tape recording of the X, Y, Z coordinates of incremental, scanned areas. The magnetic tape output will be used to control a plotter for the production of contours or an optical high resolution printer for printing color or black and white orthophotographs. It will also provide a permanent record of terrain elevation data for a digital data bank and other applications.

(5) **Analytical Stereoplotter.** While the Corps of Engineers was pursuing the development of automatic compilation equipment, the U.S. Air Force in the late 1950's undertook a parallel development of the analytical stereoplotter. The prime contractor for this development was Ottico Meccanica Italian (OMI) Corporation of America. OMI of Rome, Italy, fabricated the mechanical and optical systems in the instrument, and the subcontractor, Bendix Corporation, Southfield, Michigan, fabricated the control computer and associated electronic systems.

The first analytical plotter, the AP-1, was delivered to the Air Force in 1961. Subsequently, improved models, the AP-2 and the AS-11A, were developed by OMI under Air Force contract; and in 1962, action was initiated by GIMRADA to procure one of these instruments for test. Later, in August 1963 another instrument was procured for the Army Map Service. The first instrument was delivered to the Army Map Service in August 1964. Delivery and final acceptance of the second instrument were completed at GIMRADA in April 1965, and an exhaustive and detailed engineer test program was implemented. This testing continued somewhat intermittently over the next 3-year period, and a report of these tests was published in November 1969.[284]

The AS-11A tested consisted of a relatively simple, highly accurate, mechanical-optical stereoscopic viewing instrument, which was controlled by a stored-

283. "High Resolution Orthophoto Output Table (HIROOT)," Final Report, Singer-General Precision, Link Division, July 1969.

284. F. Raye Norvelle, ETL 50-TR, "Tests and Evaluation of the AS-11A Stereoplotter," November 1969.

program digital computer, and an output coordinatograph. It was automatic only to the extent that interior, relative and absolute orientation were accomplished by computer assist. Operation of the instrument was manual with X and Y handwheels and Z footwheels as in conventional stereoplotters. The computer solved the photogrammetric equations, controlled the motions of the instrument, could be programmed to accommodate any two photographs that could be geometrically defined, and could provide corrections for earth curvature, atmospheric refraction, lens distortion, film shrinkage, and other systematic distortion.

As a result of tests and evaluation, it was concluded that the accuracy of the AS-11A analytical plotter was equal to or better than the geometric fidelity of most precision cartographic cameras; given adequate 6-inch focal length, frame photography, 20-foot contours could be drawn from 60,000-foot photos. The AS-11A was also more versatile than previously developed analogue stereoplotters, and the concept of the computer-controlled stereocomparator provided a satisfactory instrument for accommodating frame and panoramic photography or any other type photography for which the computer can be programmed.

Further development of the analytical plotter ultimately produced the AS11B/C system. This system provided an electronic orthophotoscope capability as an automatic image correlation system to perform automatic compilation of orthophotographs and form line contour charts and record on magnetic tape terrain-surface coordinates during the orthophoto compilation—capabilities similar to those provided in the UNAMACE and the APE.

(6) **Digital Mapping System.** The exploratory development of a completely digital approach for automatic map compilation, wherein the pictorial information is digitized, spot by spot, into values representing grey scale levels, and this digitized information is analyzed and manipulated in a general-purpose computer and subsequently output through appropriate recording means to produce orthophotographs and contours, was started by the Topographic Engineering Department, ERDL, in the late 1950's. In the period 1961 to 1964, under successive contracts of GIMRADA, the International Business Machines Corporation, Kingston, New York, conducted experiments using the IBM 7094 computer and an experimental digital scanner printer modification of a government furnished Wild STK-1 stereocomparator. The experiments conducted under these investigations[285] [286] produced orthophotos and contours of sufficient quality to prove the technical feasibility of automatic mapping by digital techniques.

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[285] "A Digital Automatic Map Compilation System," Final Report, International Business Machines Corporation, July 1962.

[286] "Optimized Digital Automatic Map Compilation System," Final Report, International Business Machines Corporation, July 1964.

A contract to continue this exploratory development was awarded to the ITEK Corporation in 1965 to produce the data processing techniques and programs and the associated precision input-output instrumentation. This proved to be an overly ambitious program within the then state-of-the-art, and the contract was eventually terminated.

After this unfortunate experience, the digital mapping program remained in limbo for the next few years until 1969 when in-house investigations were resumed, and the operations to be performed with such a system were studied in some detail. As a result, it was properly decided that the best approach was to investigate data processing concepts in depth and to develop mathematical algorithms which would permit optimum computer processing for correlation.

To pursue this course and to ensure that diversified approaches would be investigated, two separate contracts with identical objectives were awarded in October 1970, one with the Wolf Research and Development Corporation and one with the Keuffel and Esser Company. In-house investigations were implemented to investigate the micro-characteristics of aerial photography which is fundamental to determine the best element or spot size and optimum number of shades of grey required to define the pictorial content adequately.

It was planned to pursue this development actively in the 1970's in view of the projected potential of this approach for increasing the speed of compilation and the quality. It was considered in 1970 that the digital approach could provide the basis for the next generation of automatic map compilation equipment.

(7) **Radar Mapping.** Although studies and investigations of radar mapping had been on a continuing basis through the 1950's, it was not until the beginning of the 1960's that radar sensor technology had advanced to the point where new design concepts and techniques were producing high-resolution radars capable of producing radar imagery with increased geometric fidelity, and the potential application of radar to military mapping became more realistic. Research and development efforts in this area were therefore intensified. A series of significant in-house and contractual programs was conducted not only to determine the feasibility of various approaches to radar mapping but also to develop concepts for the radar ground data reduction system. These studies and investigations also provided the basis for establishing requirements for radar sensor systems suitable for mapping applications. These requirements were provided to the U.S. Signal Research and Development Laboratories and the U.S. Air Force through established liaison channels as guidance in advanced radar sensor development.

The major in-house and contractual studies of the 1960 to 1970 period in chronological order of their completion were:

(a) 1961–Extraction of Mapping Detail from Radar Photography[287]

(b) 1962–Radar Network Adjustment[288]

(c) 1963–Evaluation of Coherent Radar Photography[289]

(d) 1963–Planimetric Radar Mapping System[290]

(e) 1964–Feasibility Test of 3-D Radar[291]

(f) 1965–All-Weather Mapping System Study[292]

(g) 1966–Evaluation of the AN/APQ-97 as a Radar Mapping System[293]

(h) 1966–Stereo Radar Techniques Study[294]

(i) 1968–Radar Mapping of Panama[295]

(j) 1968–Topographic Radar Mapping System Design Study[296]

(k) 1968–Interferometer Data Reduction Study[297]

(l) 1970–Stereo Radar Analysis of New AN/APQ-102(XA-2) Side-Looking Radar, Raytheon Company/Autometric Operation

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287 "Extraction of Mapping Detail from Radar Photography," Goodyear Aircraft Corporation, Phase I, December 1960, Phase III, November 1961.

288 "Radar Network Adjustment," Final Report, Northrop Corporation Space Labs, October 1962.

289 L. F. Ayers, Jr., GIMRADA 18-TR, "Evaluation of Coherent Radar Photography," November 1963, CONFIDENTIAL.

290 "Planimetric Radar Mapping System," Goodyear Aerospace Corporation, 9 Monthly Progress Reports, January Through September 1963, CONFIDENTIAL.

291 "Feasibility Test of a Proposed 3-D Radar System," Final Report, Goodyear Aerospace Corporation, February 1964.

292 "All-Weather Mapping System Analysis and Equipment Study," Final Report, Goodyear Corporation, December 1965, CONFIDENTIAL.

293 R. A. Hevenor, GIMRADA 31-TR, "Evaluation of the AN/APQ-97 as a Radar Mapping System," August 1966, CONFIDENTIAL.

294 "Stereo Radar Techniques Study," Phase I, Volume I, Analysis, Raytheon Corporation/Autometric Operation, Interim June 1966, Supplement June 1966, SECRET.

295 "Mapping from Side-Looking Radar," Final Report, Raytheon Corporation, Autometric Operation, July 1968.

296 "Topographic Radar Mapping System Design Study," Final Report, Goodyear Aerospace Corporation, December 1968.

297 "Interferometer Data Reduction Study," Final Report, Westinghouse Defense and Space Center, 1969, SECRET.

Some of these investigations used real radar imagery. Notable are in-house studies of the AN/APQ-97 side-looking radar reported in GIMRADA Technical Report 31-TR. These studies established the basic feasibility of stereo radar mapping.

To evaluate further the AN/APQ-97 radar and to determine the overall feasibility of producing topographic maps and radar photo mosaics from side-looking radar presentations, an experimental program, "Radar Mapping of Panama" ("Project Ramp"), was conducted in 1967 and 1968. The data acquisition portion of the project was contracted to Westinghouse Aerospace Corporation and the data reduction and compilation portion of the project was contracted to Raytheon Company, Autometric Operation. The products of this project were an original map of the Darien Province of Panama, computer programs used in the data reduction, and techniques of data reduction useful in radar mapping. This project dramatically demonstrated the feasibility of producing topographic maps from radar data.

The stereo radar analysis of the new AN/APQ-102 (XA-2) radar utilized real radar data and the specific applicability to 1:50,000 and 1:250,000 scale topographic mapping was tested. The two basic stereo configurations, opposite side and same side, were tested under various conditions relating to the data-reduction technique, control, and image coordinate weighting. The results indicated that this radar, using stereo techniques, had much promise for all-weather, day-night mapping at 1:50,000 and 1:250,000 scales.

These studies progressed through the decade of the 1960's: and, as a direct result several prototype items of data reduction equipment were developed. In the early 1960's, three items were produced; a Radar Sketchmaster (Fig. 111),[298] developed under contract by Aero Service Corporation in 1960 and 1961, a Radar Presentation Resitutor (Fig. 112),[299] developed under contract by Belock Instrument Corporation, College Park, New York, in 1960 and 1962, and a Radar Presentation Viewing and Measuring Instrument, (Fig. 113),[300] developed under contract by Boller and Chivens, Inc., South Pasadena, California, in 1960 to 1963. In the mid-1960's, a Radar Image Mapper was designed and constructed under contract by Singer-General Precision, Inc., Link Division, Sunnyvale, California (Fig. 114). This instrument was developed specifically for the RACOMS. These developments served to advance the state-of-the-art in radar mapping, but they were all soon superseded by much improved and highly sophisticated items of radar data reduction equipment developed in the late 1960's. These

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298 Clifford J. Crandall, GIMRADA 20-TR, "Radar Sketching Device," January 1965.

299 Clifford J. Crandall, GIMRADA 29-TR, "Test and Evaluation of the Prototype Side-Looking Radar Restitutor," April 1966.

300 Clifford J. Crandall, GIMRADA 22-TR, "Side-Looking Radar Presentation Viewing and Measuring Instrument," January 1965.

Fig. 111. Radar Sketchmaster.

items were the Universal Radar Signal Processor (Fig. 115) built by Goodyear Aerospace Corporation, Litchfield Park, Arizona; the Orthographic Radar Restitutor (Fig. 116) built by Singer-General Precision, Inc., Link Division, Sunnyvale, California; and Radar Stereo Equipment (Fig. 117), also built by the Goodyear Aerospace Corporation, Litchfield Park, Arizona.

The Universal Radar Signal Processor (correlator) was designed to process accurately all existing and anticipated coherent radar signal film to produce unrestituted radar imagery film suitable for map compilation at 1:50,000 and 1:250,000 scales. The Orthographic Radar Restitutor was designed to remove all the distortions inherent in radar imagery, including displacements due to relief, to produce a radar

Fig. 112. Prototype Side-Looking Radar Restitutor (1962).

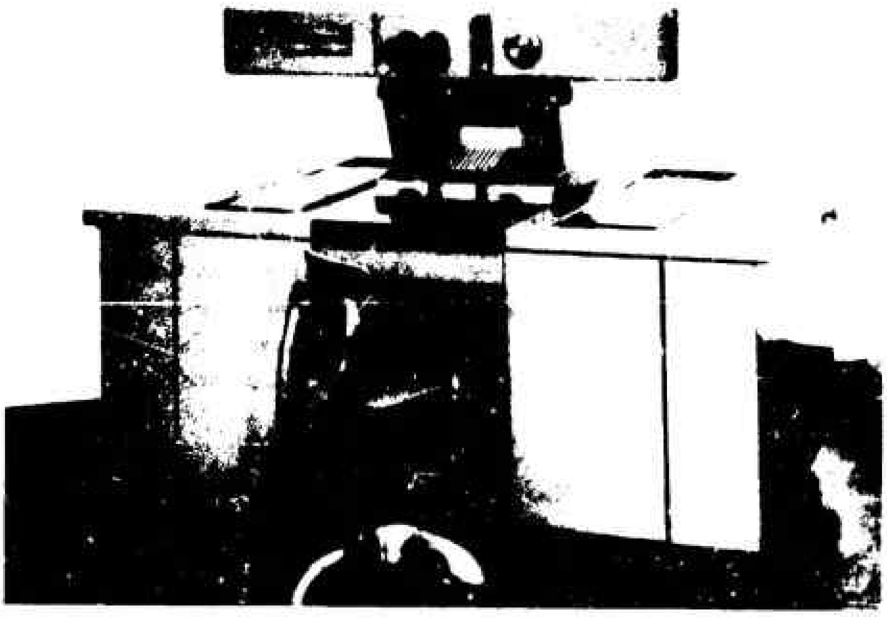

Fig. 113. Side-Looking Radar Presentation Viewing and Measuring Instrument.

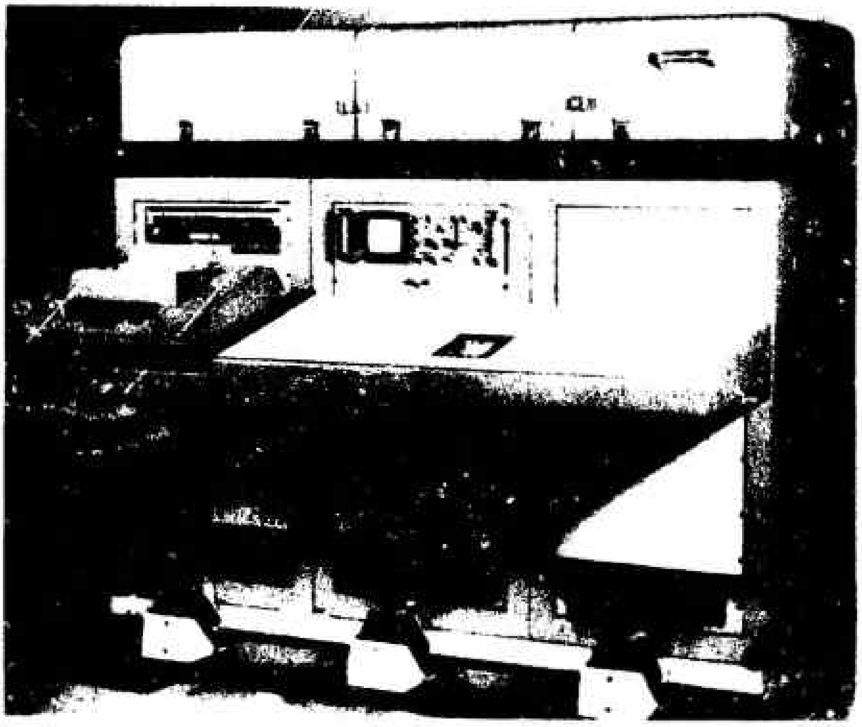

Fig. 114. Radar Image Mapper.

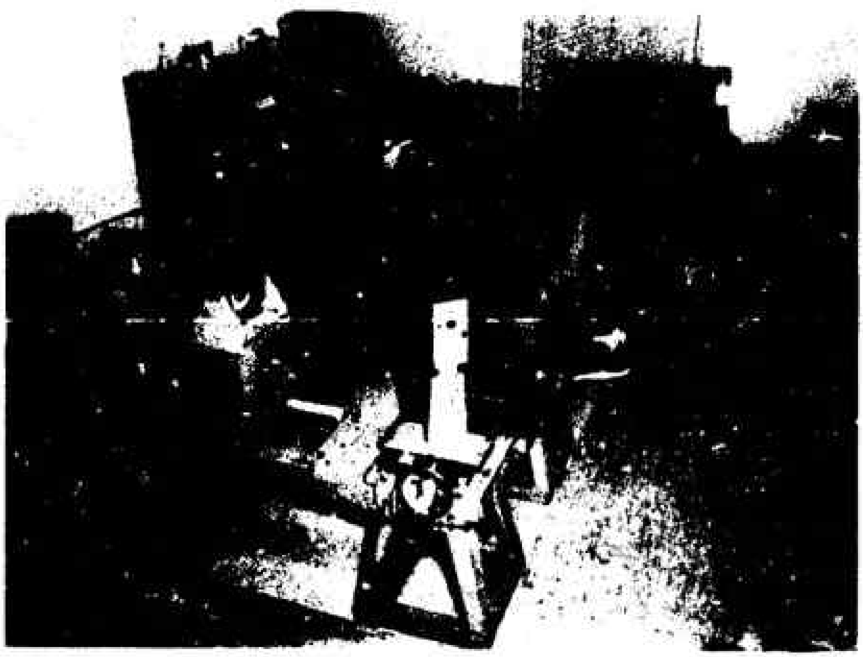

Fig. 115. Universal Radar Signal Processor.

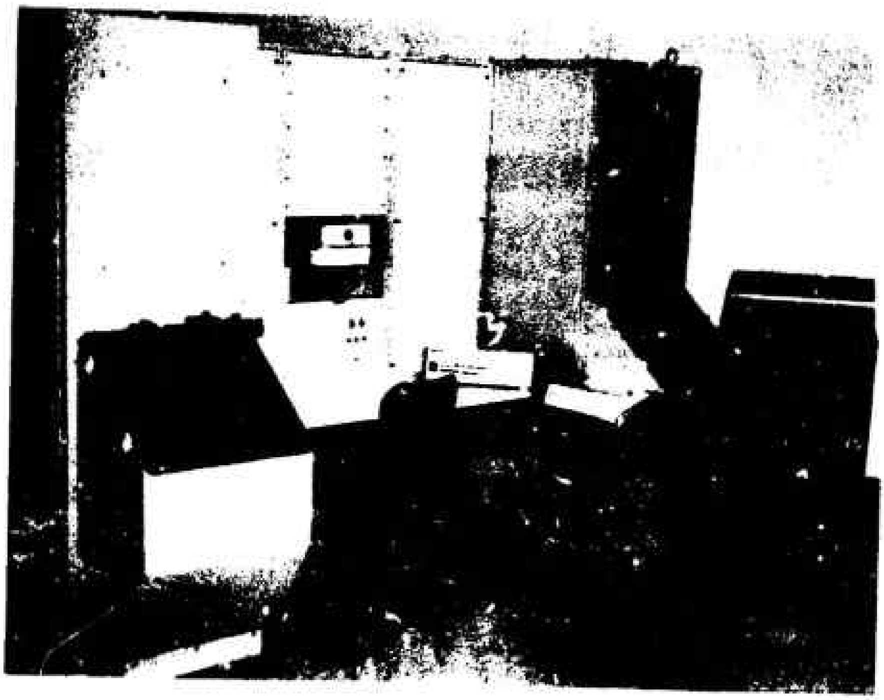

Fig. 116. Orthographic Radar Restitutor.

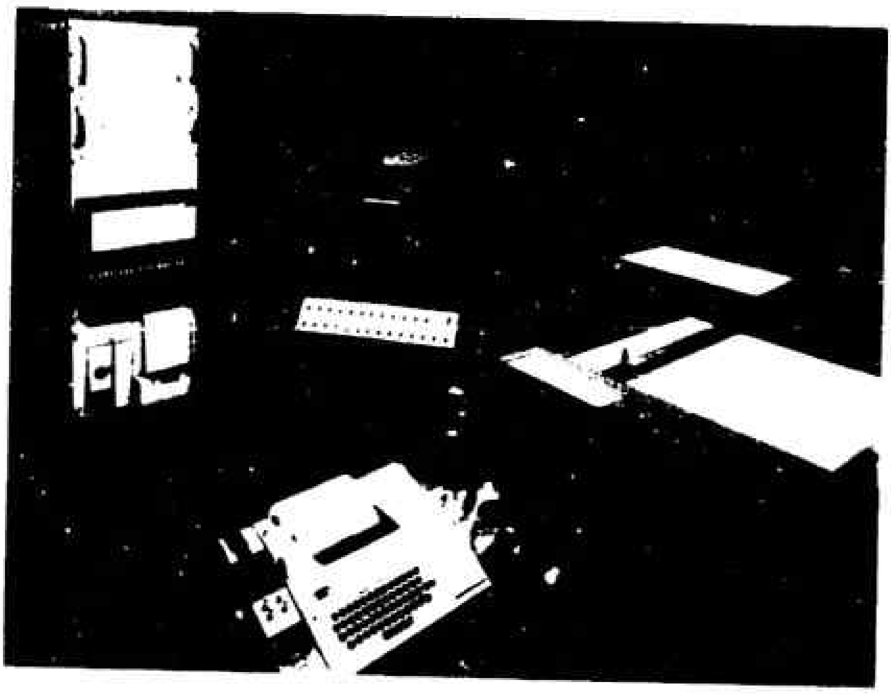

Fig. 117. Radar Stereo Equipment.

orthophotograph. The Radar Stereo Equipment was designed to provide a stereo mensuration capability to compile elevation information from a radar stereo model. It employed the analytical approach where the stereo-geometry was modeled mathematically under the control of a small computer.

Based on experience with these developments, a concentrated effort was planned for the early 1970's to develop an operational radar mapping system to be implemented at the Production Center, TOPOCOM.

(8) Mapping from Reconnaissance Photography. Equipment and techniques for using high-resolution reconnaissance photography for map compilation and map revision became a particularly acute problem in the 1960's. In many instances, reconnaissance photography was the only recent coverage available; and, although not ideal for the production of Class A topographic maps, it was necessary to do the best job possible with the resources available. Some sort of map was better than none at all.

In 1964, GIMRADA had procured an instrument called the Universal Analog Rectification System (Fig. 118) for test for application to this type of problem. The application of this equipment at that time was visualized for updating existing map coverage. Its procurement for test was an outgrowth of studies in the late 1950's and early 1960's on map-revision techniques and equipment. These studies, particularly one by Mark Hurd Survey, Inc., in the late 1950's, had produced only concepts of techniques and equipment which were considered too complex and too heavy for field use, particularly for RACOMS.

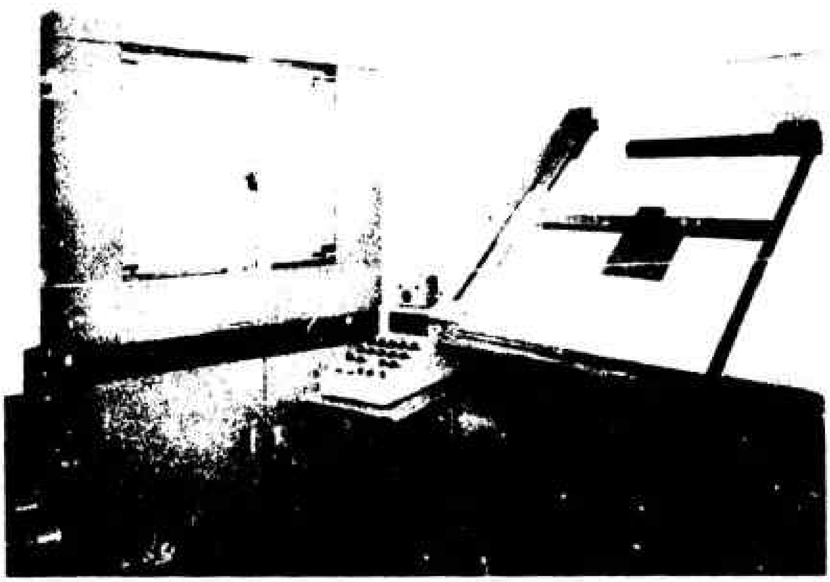

Fig. 118. Universal Analog Rectification System.

The Universal Analog Rectification System was essentially an XY coordinate plotter, with analog computer control, coupled with an input coordinatograph. Detail traced in the photograph on the input coordinatograph table was output in restituted format on the XY coordinate plotter. It was designed to accommodate frame photography of all focal lengths greater than 3 inches, with tilts of 0° to 85° and also to accommodate panoramic photographs with pitch angles of 0° to 25°, roll angles of 0° to 5° and scan angles up to ±60°. It also had provisions to correct for relief displacement. It was built by Electronic Associates, Inc., and was delivered to GIMRADA in January 1964. Tests of the equipment in 1964 and 1965,[301] for possible application in RACOMS showed in general that it did perform as intended and that it was suitable for Class B map revision and low accuracy planimetric mapping. It was later included for test in one of the modules of the RACOMS.

While testing of the Universal Analog Rectification System was in progress, the Army Map Service developed an urgent requirement for equipment to accommodate reconnaissance photography, both frame and panoramic. In November 1965, GIMRADA received Army Map Service requirements for a Reconnaissance Photo Stereoplotter. About the same time, it was learned that the Air Force, through Rome Air Development Center, had contracted with Bendix Corporation for a Chart Analysis Device (CAD) (Fig. 119) which was essentially an analytical plotter designed for reconnaissance photography, basically similar in approach to the AS-11a analytical plotter but with analog computer control rather than digital.

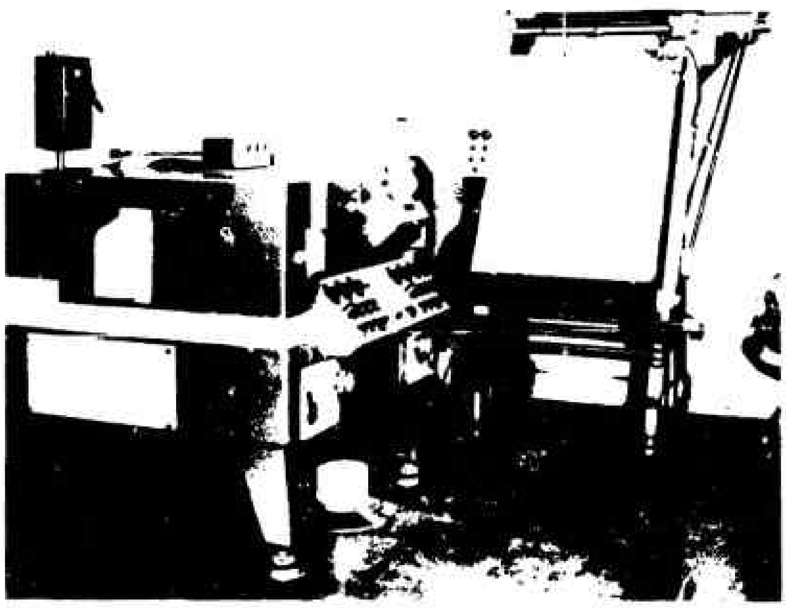

Fig. 119. Chart Analysis Device (CAD).

[301] Frank Klimavicz, GIMRADA 24-TR, "Universal Analog Rectification System for Map Revision," August 1965.

On review of the AMS requirements and the procurement documents for the CAD, it was concluded that the CAD was the potential solution to the immediate AMS problem; and, early in 1965, Rome Air Development Center was requested to procure an additional instrument for test by GIMRADA. Funds were transferred to RADC for this purpose.

In the meantime, AMS indicated a specific requirement for rectifying printer equipment capable of processing long focal length reconnaissance photography for photomap production. AMS furnished specific technical characteristics to GIMRADA in April 1965 calling for equipment for angular tilts of 24.5° and 49°, nominal camera focal length of 36 inches, and format of 18 inches by 18 inches consisting of two 9-inch by 18-inch segments. Rectification of this photography at a 0.5-magnification was desired.

Based on these requirements, specifications for two instruments, one for the 24½° tilt photography and the other for the 49° tilt photography (Figs. 120 and 121) were prepared and contract negotiations were started in July 1965. These negotiations had to be cancelled, however, when it was found that there was no lens available for the 49° printer. It was decided to change the specification to provide for an initial 2X reduction of the photographs before restitution. A contract for the two instruments was eventually awarded to Keuffel and Esser in April 1965, about 1 year after the initial requirement had been received.

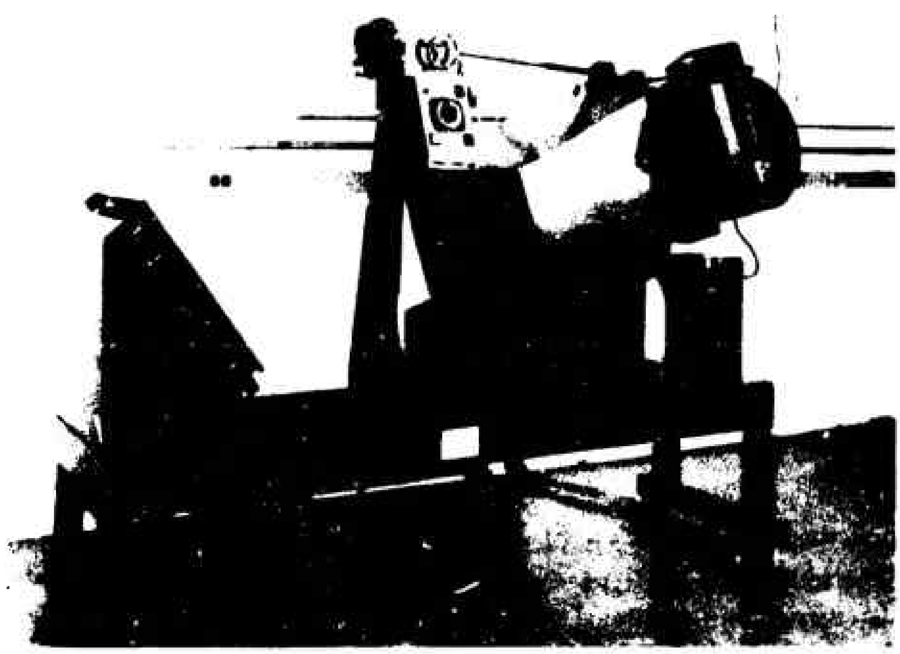

Fig. 120. Transforming Printer--24½-Degree.

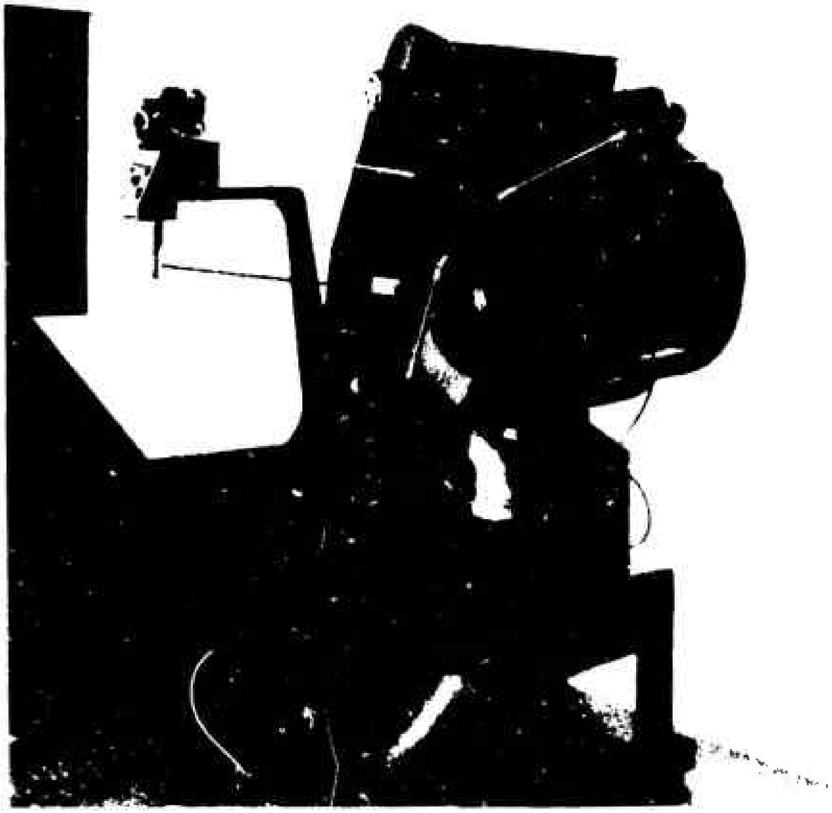

Fig. 121. Transforming Printer—49-Degree.

Paralleling the effort on the two transforming printers, GIMRADA, by transfer of funds to RADC, started procurement of another Air Force developed item for test purposes in April 1965. This item was the Electro-Optical Rectifier, being developed by the Air Force by Fairchild Camera and Instrument Corporation (later Fairchild Space and Defense Systems). In July 1965, GIMRADA started work on a purchase description for a stereoplotter called the Pan Scan Plotter, for panoramic photography. This was for special projectors designed to fit the AMS M-4 Plotter frame with film holders for 12-inch, 18-inch and 24-inch focal length panoramic photography. A fixed-price contract for this development was awarded to Photogrammetry Inc., Rockville, Maryland, in August 1966.

The development of the 24½-degree and 49-degree transforming printers proceeded without major incident or delay. Both printers were delivered to GIMRADA in mid-1967 and, after acceptance and engineering tests,[302] were transferred to Army Map Service for operational use in September 1967.

[302] George S. Barber and J. Wiley Halbrook, ETL 40-TR, "Transforming Printers: Acceptance and Engineering Tests," May 1968.

The CAD and the Electro-Optical Rectifier programs were quite another story.

The CAD was delivered to GIMRADA in September 1966; and, before final acceptance was completed, trouble developed with the equipment. However, engineer testing was started in March 1967, even though the equipment had not been repaired at that time for panoramic photography. After repeated problems with the servo systems, computer malfunction, and problems with potentiometer calibration, it was finally decided in August 1969 that further testing would serve no useful purpose and further work on the CAD was cancelled. Eventually, in July 1970, the equipment was placed on loan to the U.S. Geological Survey for 1 year.

The Electro-Optical Rectifier was delivered to GIMRADA in August 1966, but it was not in satisfactory operating condition and was picked up by the contractor and returned to his plant for repair in May 1967. It was not until almost 2 years later that the equipment was considered ready for delivery to the Government. In the meantime, it had been decided to forego engineering tests at ETL and to deliver the Electro-Optical Rectifier directly to TOPOCOM.

In January 1969, it was delivered to TOPOCOM, but installation and calibration of the equipment in accordance with Air Force specifications was not completed until May 1970. In January 1970, ETL recommended to TOPOCOM that engineering testing of the Electro-Optical Rectifier not be performed since such testing was no longer justified.

The Pan Scan Plotter development, contracted in August 1966, also faced repeated delays in completion. Initially, the program was delayed by late delivery of the M-4 Plotter to the contractor. Then, the program was delayed by problems with the projection lenses. The contractor still had not delivered the equipment by December 1970 when preliminary acceptance tests were suspended while the contractor investigated ways to improve the focus of off-axis imagery.

Another development of the 1960's under the program on mapping from reconnaissance photography was the Reconnaissance Photo Restitutor. The concept for this item was a piece of equipment which would restitute high-resolution reconnaissance photo imagery automatically to position it bit by bit in the same relative plan position as shown on a lower resolution photograph or orthophotograph. Initial studies of the image correlation problems associated with this approach were made by the Vidya Division, Itek Corporation, in the mid 1960's.[303] This study did not produce a reliable way in which such a correlation could be accomplished.

303. "Study of Panoramic-Metric Image Matching for Photogrammetric Instrumentation," Final Report, Itek Corporation, Vidya Division, Palo Alto, California, April 1965.

However, in April 1967, a procurement package for a Reconnaissance Photo Restitutor was completed; and, after revision as required for suitability for UPDRAMS and RACOMS, contract negotiations were initiated in July 1967. Contract negotiations for this item were not completed until November 1968; because, after the initial proposals were received in September 1967, it was found necessary to review the requirements of the specifications to eliminate those that would not contribute directly to determining the efficacy of the approach. With the revised specifications for a less ambitious program, it was necessary to solicit new proposals from the potential contractor. The CPFF contract for development was eventually awarded to Itek Corporation in November 1968.

By March 1969, the design plan had been approved, and the Honeywell 316 computer had been selected as suitable for the equipment; however, by May 1969, it was obvious that there would be a large cost overrun to complete the development and the contractor was requested to delay major outlays pending a re-examination of the justification for the development. Finally, in June 1969, the decision was made to direct the contract toward a feasibility study only rather than hardware; and, in August 1969, the development contract was terminated due to high cost and other factors.

This was another instance in which the development proved to be too ambitious and somewhat premature until full feasibility had been established through breadboard analysis of critical areas of development. Coincidentally, the same contractor was involved in both of these terminated programs.

This program of the 1960's to develop means for utilizing reconnaissance photography for mapping again dramatically demonstrated the complication and difficulties involved, as did the World War II work in development of equipment and techniques for using tri-metrogon photography. Yet, as long as reconnaissance has priority over mapping when it comes to the allocation of resources to data collection, it is a foregone conclusion that in many military situations only reconnaissance coverage will be available. The most valid approach to the utilization of such photography at the end of the 1970's was the UNAMACE or the APE. These equipments are rather complex, but this is a factor which cannot be avoided in a system applicable to compilation from a wide variety of input photography.

(9) **Rapid Combat Mapping System (RACOMS).** Although the project for the development of RACOMS was initiated officially in July 1961, the evolution of the concept can be traced back to the mid-1950's. In June 1956, the Continental Army Command directed the conduct of Exercise Red Arrow which included a target location test. A detachment from an Engineer Topographic Company was assigned to perform this mission, with support in the form of troop training, preparation of detailed plans,

supervision of the exercise, and preparation of a report by the Topographic Engineering Department, ERDL.

As a result of this exercise, it was concluded that a systemized approach to target location in the form of a complete and high-speed field mapping capability was needed.

In May 1958, a contract was awarded to Technical Operations, Inc., Cambridge, Massachusetts, for a study to formulate a Semi-Automatic Topographic Data Reduction and Presentation System for the 1965 to 1975 decade. Phase I of this study was completed in February 1959. It included an evaluation of existing equipment as well as equipment which would become available by 1965 for applicability to field mapping. Phase II, completed in July 1959, included a selection of equipment for automatic data processing and formulated procedures and personnel requirements for such mapping.

In March of 1960, a follow-on contract was awarded to Melpar Inc., Falls Church, Virginia, to design the system based on the Technical Operations, Inc., study. This contract was completed in September 1961. The detailed reports prepared under this contract[304] included a task list, data flow and analysis charts, equipment lists, layout of modules, and a detailed description of equipment to be employed in a Topographic Mapping System.

The objective of the task initiated at the completion of the Melpar design study in July 1961 was to develop a highly flexible mobile Rapid Topographic Data Reduction System to prepare military maps by cartographic and photogrammetric methods of a combat area utilizing aerial photographic and positional data. The project remained somewhat in limbo through 1962 although supplemental system design studies were made under contract to Autometric Corporation,[305] and a study was made by Bell Aerosystems Corporation, Buffalo, New York,[306] of attitude and positioning components for a rapid combat mapping system. It was not until 1963 that the preparation of a technical development plan was initiated by GIMRADA. This plan was published in September 1963. Also in 1963, specifications for the Automatic Photomapper, which was to be the heart of the system, were prepared and were finalized in October 1963. Subsequently, in June 1964, the development of this equipment was contracted to Bunker-Ramo Corporation, Canoga Park, California.

304. "Design of Engineering Test Model, Topographic Data System," Final Report, Melpar Inc., Volume I September 1961, Volume II June 1961, Volume III July 1961, Volume IV, August 1961, Volume V, July 1961.

305. "RACOM System Supplemental Design Study (U)," Final Report, Autometric Corporation, New York, New York, March 1962.

306. "Study of Attitude and Position Determining Components for a Rapid Combat Mapping System," Bell Aerosystems Corporation, Buffalo, New York, November 1963.

While this work was in progress, STRICOM generated an operational support requirement for a Rapid Combat Mapping System. This requirement was issued in October 1963 and was subsequently validated by the Defense Intelligence Agency. In April 1964, Department of Defense Research and Engineering directed the development of the system and the establishment of a Tri-Service Project Management Office with the Army as Program Manager. The U. S. Navy and the U. S. Air Force were to be concerned with the data acquisition aspects and the U. S. Army was to develop the data reduction subsystem. This office was established in the Office, Chief of Engineers, in July 1964, with Colonel Hamilton W. Fish, later Commander of GIMRADA, as Project Manager.

The major activity of the Office of the Project Manager was to prepare a Coordinate Technical Development Plan which was submitted to DDR&E in May 1965. In tri-service coordination of this plan, the AN/USQ-28 data acquisition system under development by the U.S. Air Force was selected as the data acquisition subsystem for the RACOMS. This office was subsequently disbanded in January 1966, and remaining responsibilities concerned with the development of the data reduction subsystem were transferred to GIMRADA.

It was not until August 1966 that an approved Qualitative Materiel Requirement (QMR) was established as CDOG paragraph 1539b(23). In the meantime, a contract was awarded to MGD Research and Development Corporation in December 1965 to develop an Electrostatic Printer for RACOMS. In January 1967, a contract was awarded to OPTO Mechanism, Inc., for a Pass Point Marking and Measuring Instrument,[307] and, in March 1967, a contract was awarded to Potomac Research, Inc., for the installation of RACOMS equipment in expansible standard van modules. Also in the period from December 1965 to January 1967, contracts were awarded as necessary and other procurement actions were taken to assemble the standard military items and off-the-shelf components commercially available for the system.

The system assembled for testing included equipments for exploitation of all the latest technological advances in mapping considered applicable in the Rapid Combat Mapping System suitable for field operations. The Engineer Test System consisted of eight expansible-side mobile shelters or modules mounted on detachable running gear to provide ground mobility (Fig. 122). All modules were transportable in a C-130 aircraft. The system was designed to produce four 1:50,000 scale orthophotomaps, with some cartographic delineation, in 48 hours and two sheets each 24 hours thereafter using data from the U. S. Air Force AN/USQ-28 Acquisition System. The modules were: (1) Operation Module (Fig. 123) which served as the control center for

[307] E. Taylor, [illegible] 5?-TR, "RACOMS Pass Point Marking and Measuring Instrument, Engineer Design Test Report," January 1970.

Fig. 122. Expansible Van on Dolly Wheels as developed for RACOMS.

the system; (2) Image Processing Module I (Fig. 124) containing an auto-dodging printer and photographic processing equipment for making diapositive plates and prints; (3) Compilation Module I (Fig. 125) containing the APE, the heart of the system; (4) Data Processing Module (Fig. 126) containing the computer, pass point marking and measuring instrument, tape recorder, and punch, etc. for analytical aerotriangulation operations; (5) Cartographic Module (Fig. 127) containing drafting tables, a coordinatograph, type composing machine, and Varityper composing machine for the required cartographic operations: (6) Image Processing Module II (Fig. 128) containing temperature controlled sink, enlarger-reducer camera, film dryer, vacuum frame and arc lamp, diazo developer, etc. for processing in support of the reproduction operations; (7) Reproduction Module (Fig. 129) containing the five-color Electrostatic Printer for reproduction of the map products; and (8) Map Revision Module (Fig. 130) containing a map revision instrument, an autofocusing reflecting project and a Radar Image Mapper, the equipment required for map revision.

Engineer design tests of the RACOMS were conducted from June 1968 through January 1970.[308-313] During the engineer design test period, a joint

[308] A. W. Stoll, ETL-ETR-70-1, "RACOMS Compilation Module, Engineer Design Test Report," April 1970.

[309] F. P. Vena, ETL-ETR-70-2, "RACOMS Image Process Module II, Engineer Design Test Report, May 1970.

[310] F. P. Vena, ETL-ETR-70-3, "RACOMS Cartographic Module, Engineer Design Test Report," May 1970.

[311] R. B. Godfrey, ETL-ETR-70-4, "RACOMS Data Processing Module, Engineer Design Test Report," May 1970.

[312] E. Taylor, ETL-ETR-70-5, "RACOMS Map Revision Module, Engineer Design Test Report," July 1970.

[313] S. Presser, ETL-ETR-70-8, "Rapid Combat Mapping System Evaluation," August 1970.

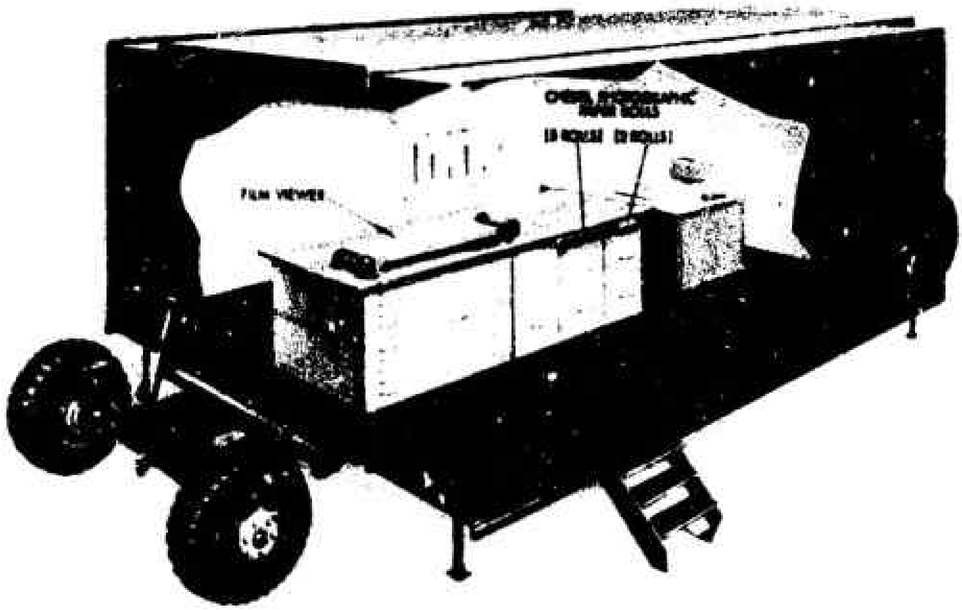

Fig. 123. RACOMS Operations Module.

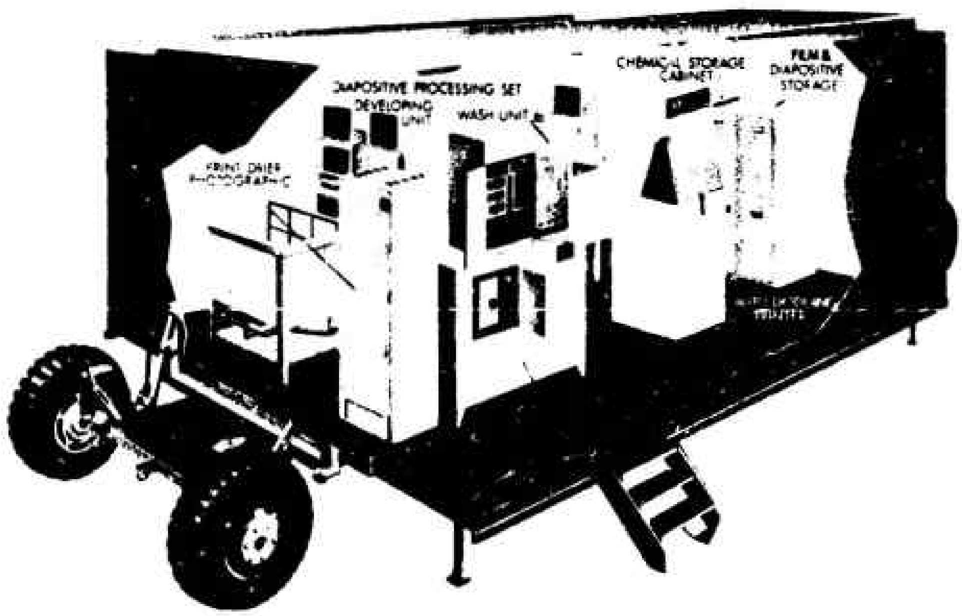

Fig. 124. RACOMS Image Processing Module.

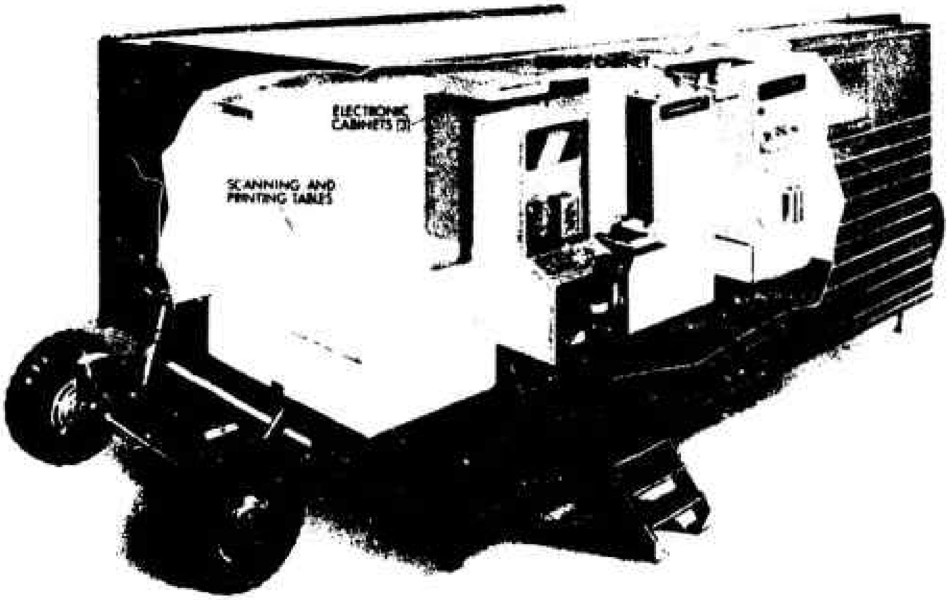

Fig. 125. RACOMS Compilation Module I—Automatic Photomapper.

CONVERSION & ADJUSTMENT

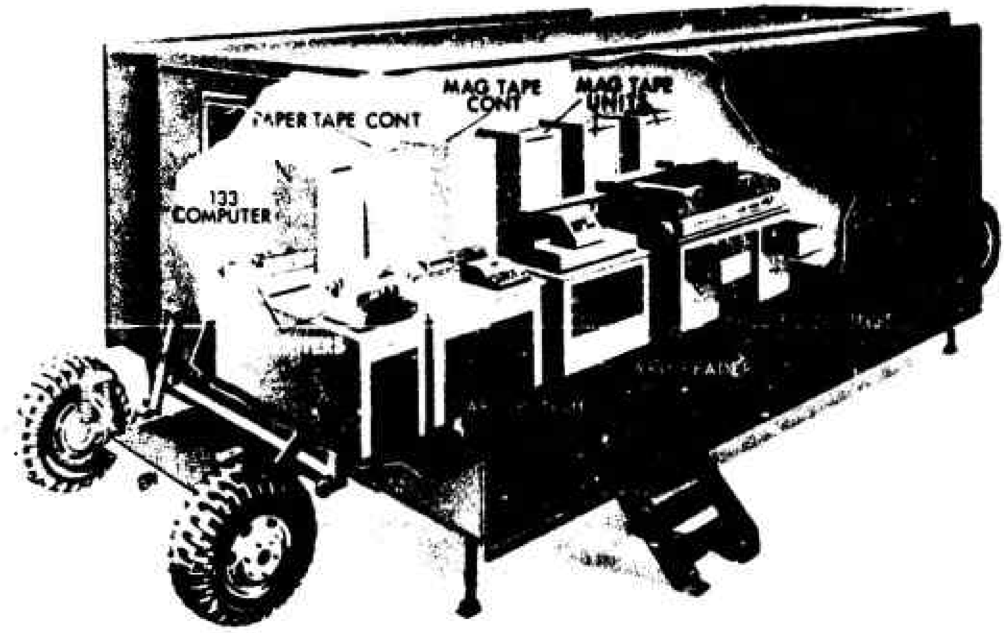

Fig. 126. RACOMS Data Processing Module.

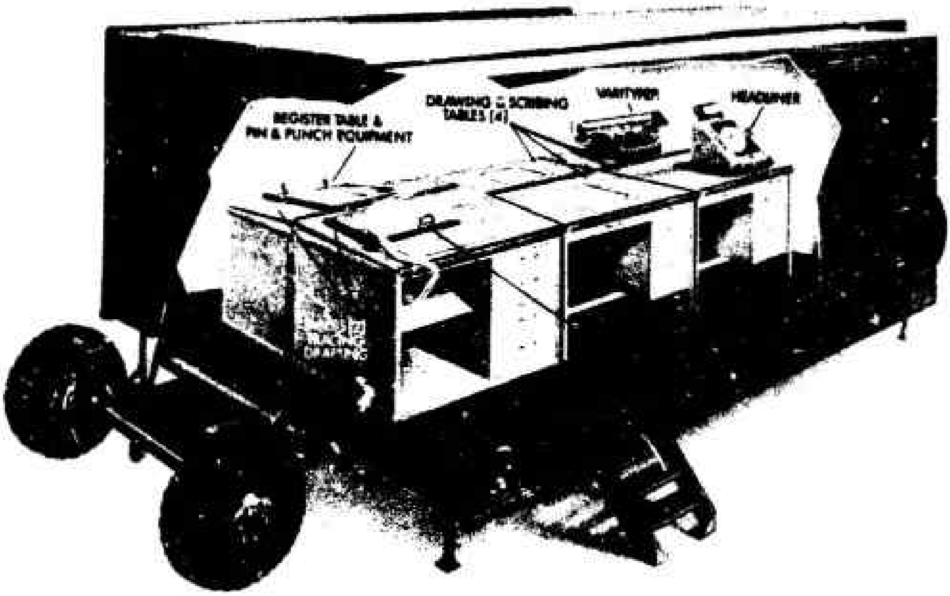

Fig. 127. RACOMS Cartographic Module.

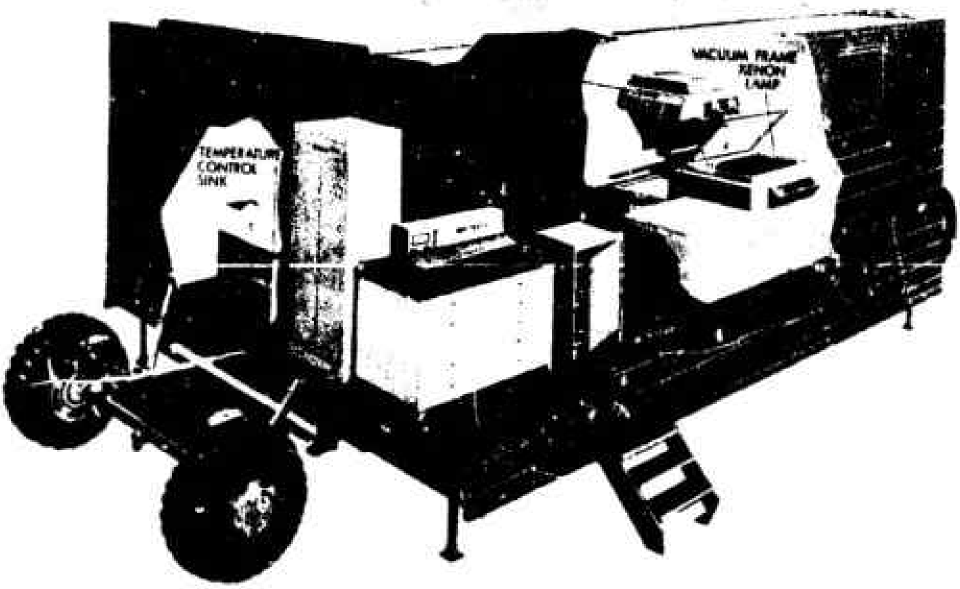

Fig. 128. RACOMS Image Processing Module II.

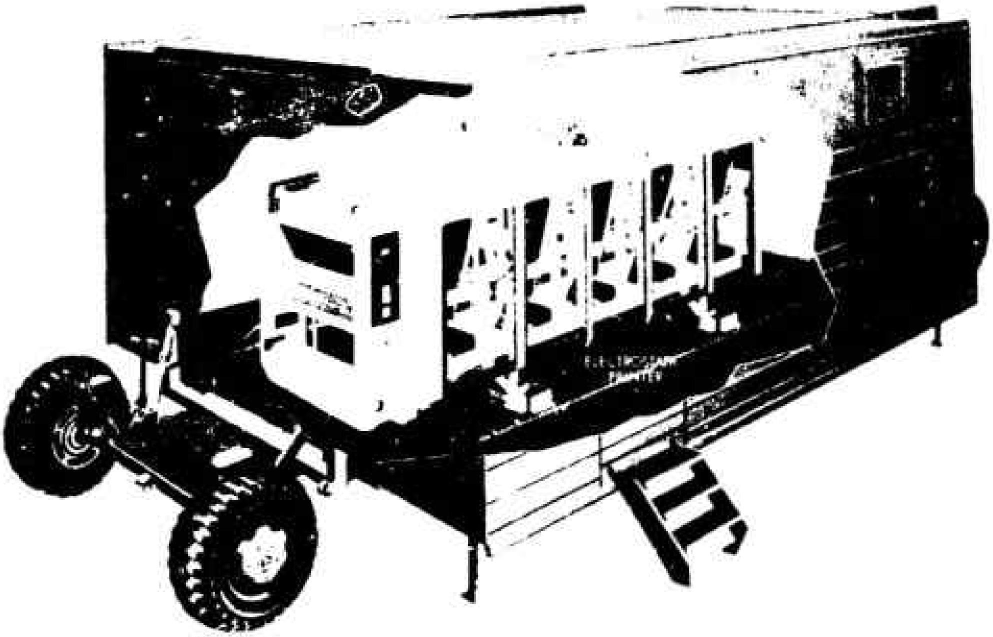

Fig. 129. RACOMS Reproduction Module.

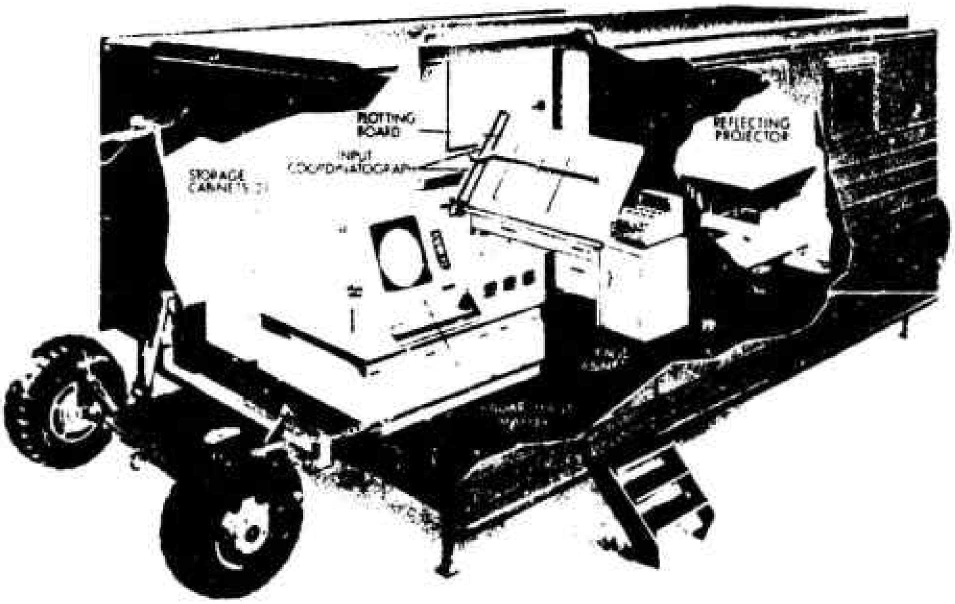

Fig. 130. RACOMS Compilation Module II - Map Revision.

Army/Air Force test of the entire system including the AN/USQ-28 acquisition system was conducted in the period June 1968 to January 1969.[314]

Further operational tests of the RACOMS data reduction system were conducted by the 30th Engineer Base Topographic Battalion in the period April through December 1970.[315]

In the joint Army/Air Force test the objective was to demonstrate the capability of the RACOMS ground subsystem to produce orthophotomaps from photography and control data collected by the airborne subsystem, the AN/USQ-28, as well as from cartographic photography collected by an operational reconnaissance aircraft, the RF-4C. The objectives of the test were only partially achieved because the USQ-28 subsystem failed to provide satisfactory control data, camera position, and attitude; and the required computer programs had not been fully developed for the reduction of reconnaissance photography. Further, a southeast area mapping project was substituted for the reconnaissance data reduction phase of the project. It was demonstrated that the ground subsystem could produce a satisfactory product when USQ-28 photography and simulated control data were used. It was further demonstrated that enlisted personnel could be trained to operate the ground data reduction subsystem.

In the engineer design tests it was found that, except for the Electrostatic Printer and the Radar Image Mapper, the equipment met the required technical performance characteristics and that the system could produce the required products. The Radar Image Mapper proved to be totally unsatisfactory because of difficulties encountered in the operation and reliability of the computer and electronic components. The Electrostatic Printer did not consistently produce products having acceptable image quality because of intermittent background tinting. The tests further showed that the specified production rate could be achieved only if the photographic input was at a scale smaller than 1:70,000 and accurate position and attitude data were furnished by the acquisition system.

The operational tests of the 30th Engineer Battalion confirmed that a trained troop unit could operate and maintain RACOMS (with limited assistance). The test report concluded that selected components of the RACOMS should be type classified and integrated into the 29th, 30th, and 656th Engineer Battalions and that the Automatic Photomapper should be phased into military type operations to replace the Kelsh and Multiplex apparatus. This was never accomplished because of a subsequent

[314] Sidney Presser, "Report on Joint Army/Air Force Test," July 1969.

[315] CW3 Roger T. Pelletier, "Evaluation of the Rapid Combat Mapping System (RACOMS)," 30th Engineer Battalion, January 1971.

decision of the Army Materiel Command not to pursue type classification primarily because of projected field maintenance problems.

(10) **Precision Enlarging Printers.** During the 1960's, GIMRADA developed three special-purpose, fixed-ratio, precision enlarging printers for special application at the Army Map Service. The first of these was developed to meet an Army Map Service requirement for a four-time enlarging printer with extremely high resolution and negligible distortion for use in the preparation of 9½- by 9½-inch glass plates and film positives from 70- by 70-millimeter negatives. It was designed and constructed by the Watson Electronic and Engineering Company, Arlington, Virginia, and was delivered to GIMRADA in May 1964. After acceptance tests, final calibration, and some design changes at GIMRADA, the printer was delivered to the Army Map Service in October 1964. Engineer design tests[316] were performed by Army Map Service personnel under the direction of the GIMRADA project engineer and were completed in January 1965.

In 1966, a requirement developed at the Army Map Service for two additional special-purpose, fixed-ratio, precision enlarging printers, one for an enlargement of 3.3 diameters from 70-millimeter negatives (Fig. 131), and the other for an enlargement of 2.0 diameters from a 4½- by 9½-inch format to 9- by 18-inch output format (Fig. 132). The contract for design and fabrication of the 3.3X printer was awarded to Watson Electronic and Engineering Company. The contract for design and fabrication of the 2.0X printer was awarded to Hoffman Corporation, Springfield, Virginia. Both contracts were awarded in February 1967, and both items were delivered to GIMRADA for acceptance in June 1968.

After acceptance and engineering tests in the later half of 1968 and early 1969, the 2.0X printer was delivered to TOPOCOM in February 1969 for service test and production use. The 3.3X printer had to be returned to the contractor in September 1968 because it did not meet the resolution requirements. No lens could be found that would meet the resolution requirements and, in October 1969, the contract was modified by reducing the resolution requirements and price. The printer was accepted from the contractor, and further development and test were suspended.

(11) **Glass Plate Processor.** Another development of the 1960's to meet a special requirement of the Army Map Service was the Glass Plate Processor for the automatic photographic processing of glass plates in images ranging from 54 by 54 millimeters to 9½ by 19 inches and suitable for operation in a white room. This item was contracted to Bar Ray Products, Brooklyn, New York, in May 1965. It was delivered to the Army Map Service in July 1966 and was finally installed and accepted after some repair and adjustment by the contractor in January 1967.

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[316] Andrew J. Bondurant and Theodore L. Fick, GIMRADA 27-TR, "Precision Enlarging Printer (4X)," March 1966

Fig. 131. Precision Enlarging Printer (3.3X).

Fig. 132. Precision Enlarging Printer (2.0X).

(12) Utilization of Color Photography for Mapping. Use of color photography for mapping was a subject of some interest as early as World War II. However, serious consideration was not given to the use of color photography until the 1960's when commercial color photography had advanced so that acquisition of high quality color aerial photography was considered practicable, the photomap was gaining acceptance as a military ma product, and certain advantages were apparent in full color portrayal of the terrain.

In the mid-1960's, GIMRADA implemented a project to investigate the application of color photography for mapping and the subsequent problems associated with its use. Two major aspects of this investigation were the photointerpretation applications and the advantages of color photography which are noted in a later section of this history. Another major aspect of the investigation was the processing and reproducing of full-color photography and photomaps, including the use of color imagery in map-compilation instruments.

To carry out investigations in these areas, steps were taken in 1967 and 1968 to equip the GIMRADA laboratory for color photography investigation. Color roll film developing equipment, automatic color processing equipment, and contact printing equipment specially designed for color work were procured and installed. Also, a Gigas-Zeiss orthoprojector was procured for the experimental production of full-color orthophotomaps in conjunction with the Zeiss Stereoplanigraph. Although of German origin and manufacture, the Zeiss Stereoplanigraph was determined to be the most expeditious approach to provide equipment for the experimentation needed in this area. There was considerable interest in the mapping community in the color orthophotomaps produced experimentally with this equipment in 1969 and into the 1970's.

While this work was in progress, other investigations were made in the automatic mapping area on the use of color imagery and also on the production by electronic scanning, using the experimental automatic map compilation equipment, of color separations for subsequent reproduction in color by conventional process color printing techniques.

At the beginning of the 1970's, these investigations were laying the groundwork for the inevitable advanced developments in the color photo application area.

(13) Photogrammetric Support for Artillery. Another significant development of the late 1960's was the provision of a photogrammetric facility in direct support of field artillery units for target-positioning application. In pre World War II days, such a concept had been advanced when Major Bagley developed the Bagley calculator – a mechanical device for determining the radial ground distance of a point from the center

of a photograph, given its photo distance and the photo scale. The device essentially corrected for relief displacement in the photograph and was intended for use with a photograph or gridded mosaic of photographs to spot true position of the point of interest.

In July 1969, a short frame multiplex unit was sent to Fort Sill, Oklahoma, to demonstrate suitability for field use in support of artillery units. Fairly good results were reported, and in March 1970 a letter was received from Fort Sill concerning the possible development of photogrammetric equipment and methods suitable for field artillery. Work started immediately in-house on a breadboard target positioning system, and in July 1970 a Kelsh plotter with digital readout was displayed at a survey and target acquisition conference at Fort Belvoir. In December 1970, procurement was initiated for a commercial Balplex Stereoplotter and a Keuffel and Esser coordinate reading system for further demonstration of an approach for a photogrammetric facility.

e. **Cartographic and Graphic Systems.**

(1) **Electrostatic Printing.** The development of electrostatic printing was one of the major projects in the graphics area in the 1960's. It was thought that a multi-color electrostatic printing machine which would print 70-millimeter color separated film chips would offer an alternate to the rather large logistic problem involved in preprinting, stocking and distributing large volumes of map sheets required for Field Army operation. World War II experience had shown that the typical Field Army required a total initial issue of 2,700,000 maps weighing 162 tons and a daily replenishment of 120,000 sheets weighing 7.5 tons. Yet, it was estimated that only about 10 percent of all the maps printed were actually used due to outdating of information, changes in battle plans, and revised strategy. With the new concepts involving highly mobile, widely dispersed army units it appeared that the problem was getting worse.

Electrostatic printing offered the possibility for printing maps as needed from microfilm chips. These maps could also be printed close to the user. Thus, all available mapping of the area of interest to a field commander would be carried by his topo troops in the form of small—perhaps of 70 millimeter—color-separated film chips. When the commander determined the need for certain maps, the applicable chips could be pulled from the file, dropped in the electrostatic printing machine, and printed at or near his headquarters.

At the beginning of the 1960's, an electrostatic printing machine concept based on a selenium transfer system using a selenium drum in conjunction with high-speed cascade image development and electrostatic transfer from drum to paper had been submitted by the Haloid Corporation as a result of their research under ERDL contract through the 1950's. Also, a demonstration model of an electrostatic printing machine

using a 22½-inch web of zinc oxide binder coated paper and liquid development had been produced for ERDL by RCA Laboratories.

Contract negotiations were implemented in 1959 for the development of a five-color electrostatic printing machine, but the basic process to be employed, selenium drum to paper transfer or liquid immersion development on zinc oxide coated paper, was left open to be evaluated with the proposals. Harris Intertype Corporation was awarded the contract to develop the equipment based on the liquid immersion approach. The two primary reasons for this selection were: the equipment would be less complex, and it appeared that image quality would be superior to that of an image-transfer system. This later was considered particularly significant in view of the foreseeable need for reproducing continuous tone copy; i.e., photomaps and mosaics.

A phased development was contracted to the Harris Intertype Corporation. Phases I and II were to design and fabricate a test model single-color machine. Phase III was to develop suitable imaging materials and paper for the process. Phases IV and V were to design and fabricate a test model multicolor machine based on experience with the single-color machine.

The single-color machine was delivered to GIMRADA in December 1961 (Fig. 133). Evaluation and test of this machine[317] demonstrated the feasibility of this approach for reproducing multicolor topographic maps for field use. (Multicolor maps were reproduced by successive passes through the machine.)

The test model of the five-color printing machine was delivered to GIMRADA in June 1963 (Fig. 134). This machine produced multicolor images on a continuously moving web of photoconductive paper by flash exposure at 8.8-diameter enlargement from 70-millimeter microfilm chips. It was capable of reproducing 2000, 22½- by 30-inch map sheets per hour after a 30-minute setup time. Evaluation and test of the machine[318] showed that it would reproduce acceptable multicolor topographic maps for field use and that the basic machine configuration was sound but that some components needed modification to increase the quality and the accuracy of reproduction.

Following these tests, two additional machines were procured for further testing. These machines were delivered in July 1965; one was retained at GIMRADA (Fig. 135) to evaluate papers and toners for the process and the other was shipped to Southeast Asia for evaluation in a field environment. In December 1965, a contract was awarded to MGD Research and Development Laboratories, Englewood

[317] Ralph L. Marzocco and Fredrrick C. Myers, GIMRADA 19-TR, "Evaluation and Test of a Single-Color Electrostatic Printing Machine for the Reproduction of Topographic Maps and Charts," January 1964.

[318] James Gladden, GIMRADA 25-TR, "Evaluation and Test of a Five-Color Electrostatic Printing Machine for the Reproduction of Topographic Maps and Charts," October 1965.

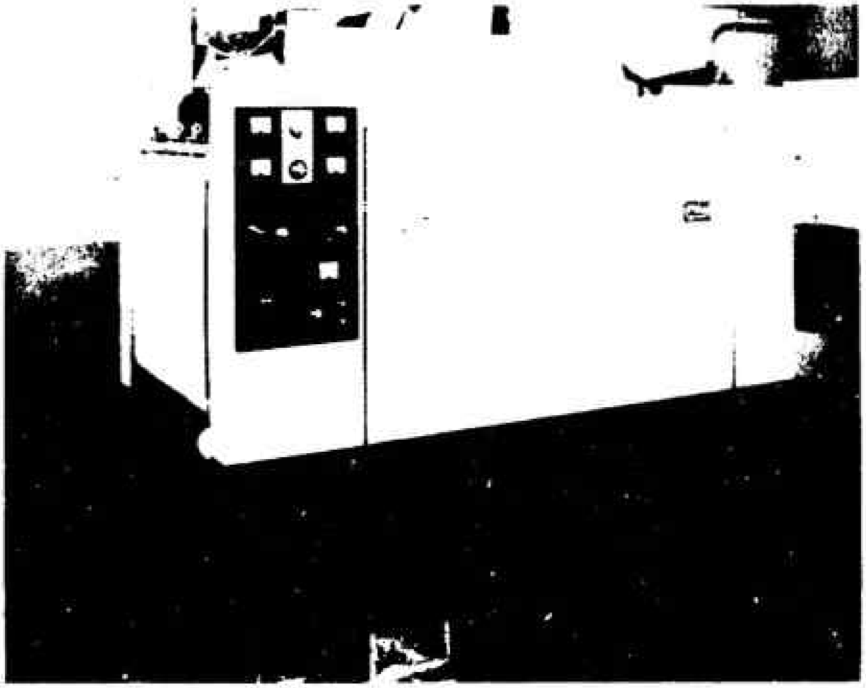

Fig. 133. Electrostatic Printing Machine—Single Color (Harris Intertype Corporation).

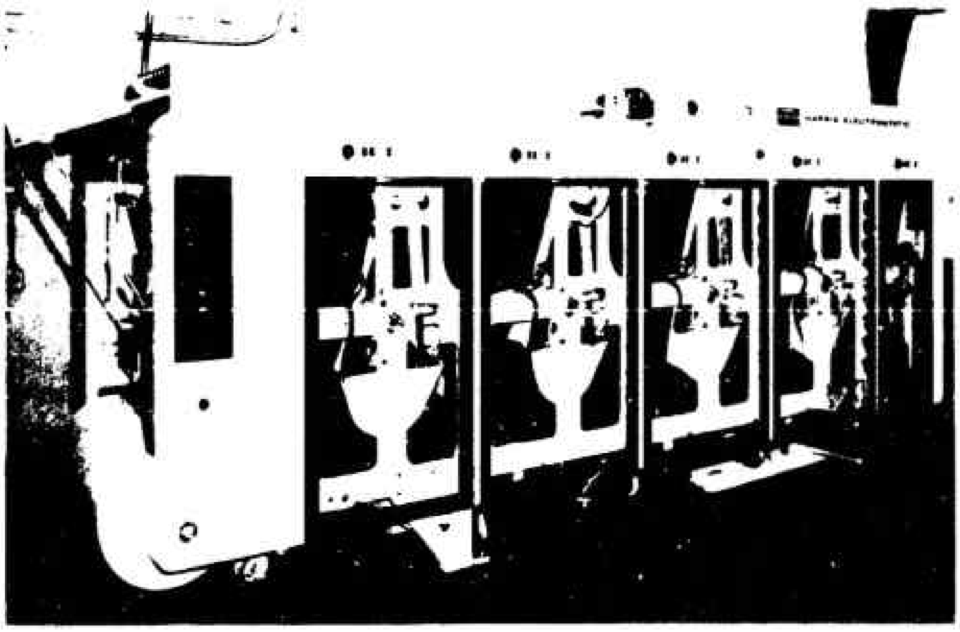

Fig. 134. Electrostatic Printing Machine—Multicolor (Harris Intertype Corporation test model).

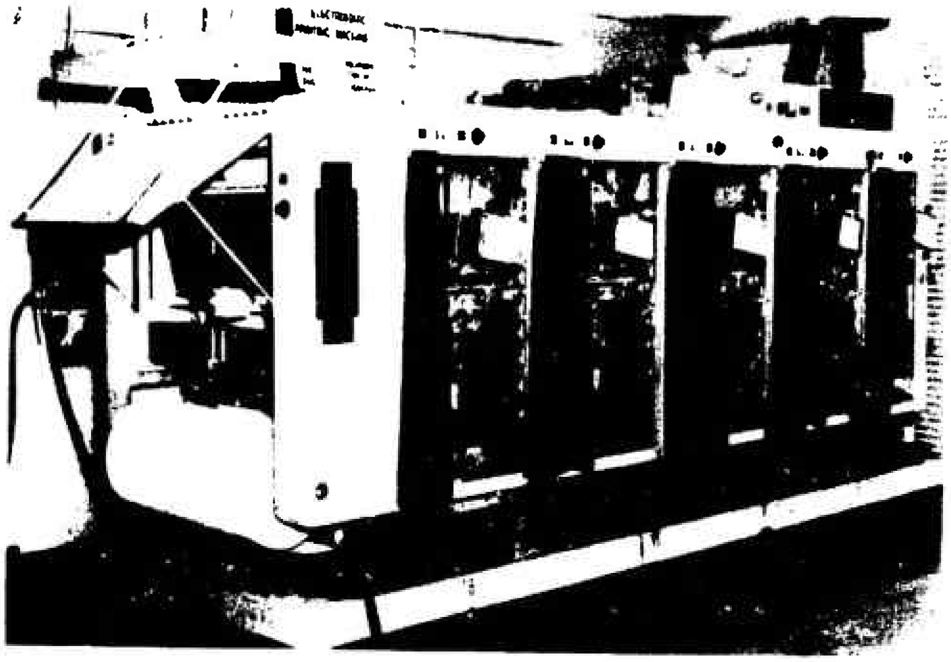

Fig. 135. Electrostatic Printing Machine--Multicolor (Harris Intertype Corporation advanced model).

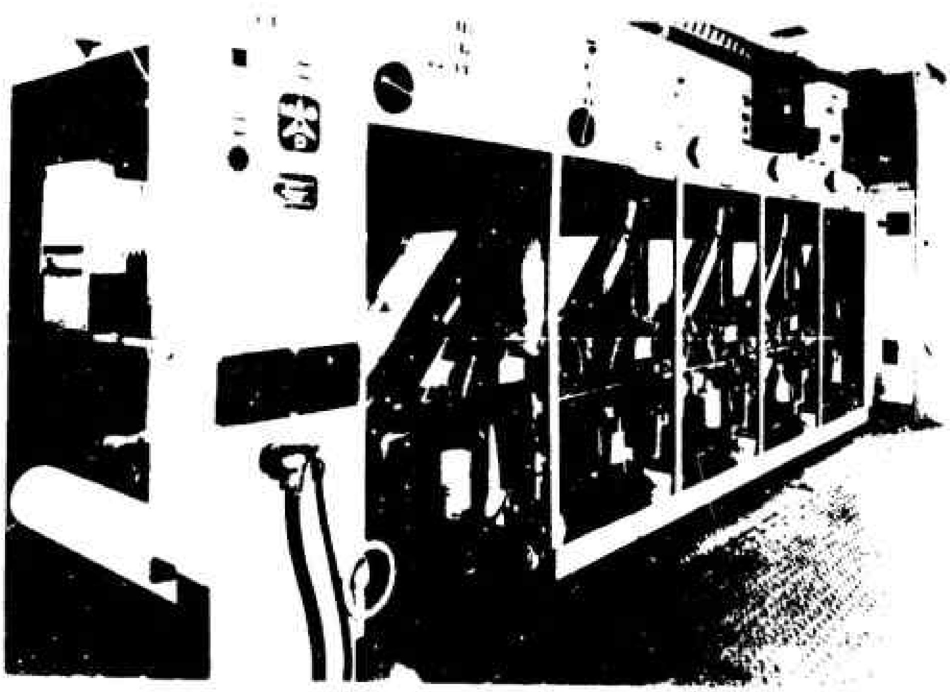

Fig. 136. Electrostatic Printer for RACOMS (MGD Research and Development Laboratories).

Cliffs, New Jersey, for an electrostatic printing machine designed for the RACOMS System. This machine was delivered in June 1968 (Fig. 136). It was similar to the previously produced machines with one major difference. A transparency holder was provided in the plane of projection in near contact with the moving web of paper. Thus, by inserting a full size transparency into the holder, a full sized reproduction could be obtained by flash exposure with the high-intensity xenon light source. The printer also had the capability of printing from 70-millimeter film chips.

In testing the electrostatic printing machine in conjunction with the RACOMS System, as noted elsewhere, consistently high-quality results could not be achieved. These results indicated that the paper and toner technology had not kept pace with the parallel machine development and that if the electrostatic printing approach was to be applied successfully in the field, further research and development would be necessary.

At the beginning of the 1970's, work was continuing on the development of the electrostatic process and materials, with specific attention to process color approach to multicolor printing for the reproduction of multicolor maps and color photography and the direct color-to-color process which would provide a one-step operation for color reproduction.

(2) Target Map Coordinate Locator (TMCL). In September 1961, the Fairchild Camera and Instrument Corporation finally delivered to GIMRADA the experimental model Target Map Coordinate Locator and a laboratory model microfilm camera and associated photographic processing equipment which had been contracted for by the Topographic Engineering Department, ERDL, in May 1958. The equipment was designed to be a companion device to electrostatic printing in the new concept of map supply and reproduction through 70-millimeter microfilm chips.

It was intended to provide users, such as artillery and missile fire direction centers and planning and higher echelon headquarters, with a facility for storage and rapid access to the rather large quantity of maps covering their areas of interest together with the means to facilitate determination of map coordinates of potential targets or for other military purposes throughout the large areas commanded by modern missile systems.

The Target Map Coordinate Locator produced by Fairchild Camera and Instrument Corporation was essentially a fixed-focus projector designed to project 70-millimeter microfilmed multicolor maps onto a rear-projection screen at 8.8 diameters enlargement. It had sufficient capacity to store 11,000 maps, any of which could be automatically selected and projected for viewing within 15 seconds. Cross hairs, visible on the screen and driven in X and Y from the operator's console, were positioned to

coincide with the grid on the projected map image. With the grid coordinates set in the readout, the cross hairs could be traversed to any selected position on the map, and the map coordinates could be read directly from dials on the console.

Engineer design tests of this machine[319] concluded that it would make possible the quantity storage of microfilmed topographic maps or photomaps, rapid access to the maps, and speedy and accurate determination of map coordinates but that further improvements in the design were needed to provide a reliable instrument and to facilitate maintenance.

In March 1963, a contract was awarded to Pollak and Skan Inc., for two improved models for engineer and service testing (Fig. 137). A third unit was built at the request of the Naval Reconnaissance and Technical Support Center (NRTSC), Suitland, Maryland.

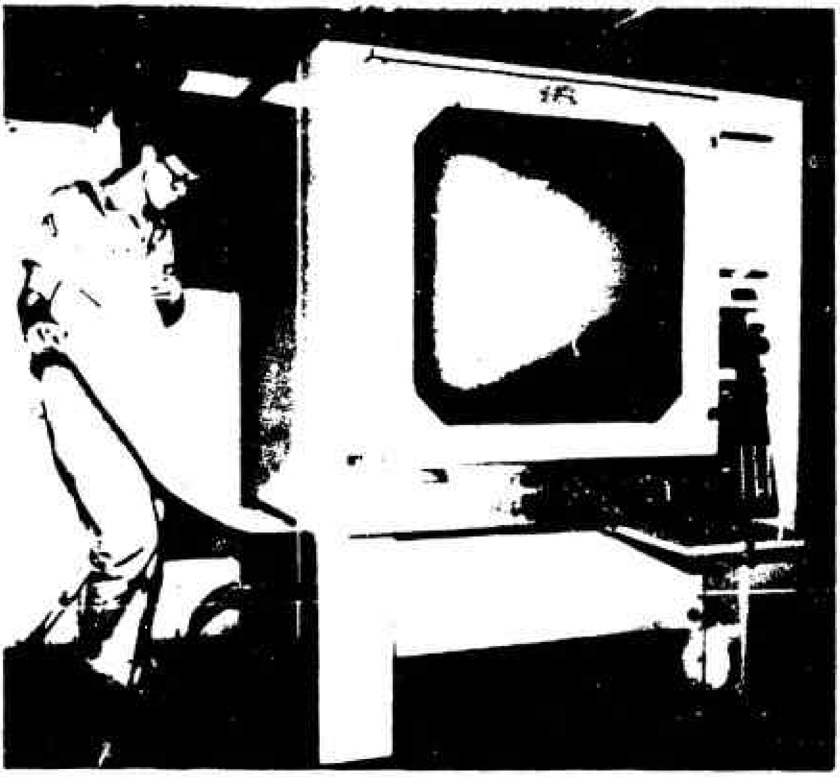

Fig. 137. Target Map Coordinate Locator with hard copy printout (Pollak and Skan, Inc.).

[319] Joseph P. Goodwald, GIMRADA 14-TR, "Test and Evaluation of Target Maps Coordinate Locator Equipment," July 1963.

Several major changes were made in these new models. A hard copy printout was added so that a limited number of copies of a projected map could be made. In addition, an overlay could be made on the projected image and then transferred and overprinted on the hard copy by electrostatic printing techniques. The storage capability was made more flexible by using 1000-microamp drums. Two of these drums could be installed in the machine for immediate use, while any number of other drums could be stored in a rack conveniently located near the machine.

These models were tested by the U.S. Army Test and Evaluation Command (TECOM), and a test report dated 10 June 1966 was prepared. However, during the test period, the requirement for the Target Map Coordinate Locator was deleted from the Combat Development Objectives Guide and further development was terminated.

Termination of development was not the end of the story on the TMCL. In October 1965, the U.S. Military Advisory Command, Vietnam, expressed interest in field testing the instrument, and one unit was ruggedized and shipped to Vietnam with a trained military operator. It was used in the Combined Intelligence Center during the period January through August 1967, was returned to the United States, and by request was transferred to the Naval Oceanographic Office, Suitland, Maryland, in January 1970. In August 1971, ETL was asked by ACSFOR to demonstrate the TMCL to a group of officers from U.S. Army Combat Developments Command and Project MASSTER (Modern Army Selected Systems Test Evaluation and Review). As a result of this demonstration in November 1971, ETL was requested to ship one TMCL to Fort Hood, Texas, for evaluation and use in project MASSTER exercises to begin in April 1972.

(3) Automatic Point Reading, Plotting, and Grid Ruling Machine. One of the recommendations of studies made in the late 1950's on improving or automating cartographic operations was that an automatic instrument designed to rule grids and plot points be developed. Prior to that time, investigations of the mechanization of these operations had resulted in the addition of manually operated coordinatographs, which incidentally were produced in Europe, to applicable sets of field equipment. Investigations of plotters commercially available in the United States revealed that none had the required accuracy, speed, and reliability required for mapping operations.

Specifications were prepared for the development of a machine that would automatically plot or read control point information and generate precision grids for map production. The instrument was to have the ability to plot and identify points either automatically with input from punched paper tape or semi-automatically with input from a keyboard. Grid lines would be scribed on coated plastic sheets or inked on suitable drafting materials. Coordinate information to generate grid lines would be inserted by punched paper tape or keyboard. When the instrument was used as a point

reader, joystick controls were to enable the operator to position the carriage with the view screen attached at random over the plotting surface. The operator would then be able to read the X, Y coordinates of any point from display tubes located on the machine control panel; or a punched paper tape and a typewritten record of coordinates could be prepared automatically as the points were located.

The development of this machine was contracted to the Gerber Scientific Instrument Corporation, Hartford, Connecticut, in February 1960. The equipment was delivered to GIMRADA in October 1960 (Fig. 138).

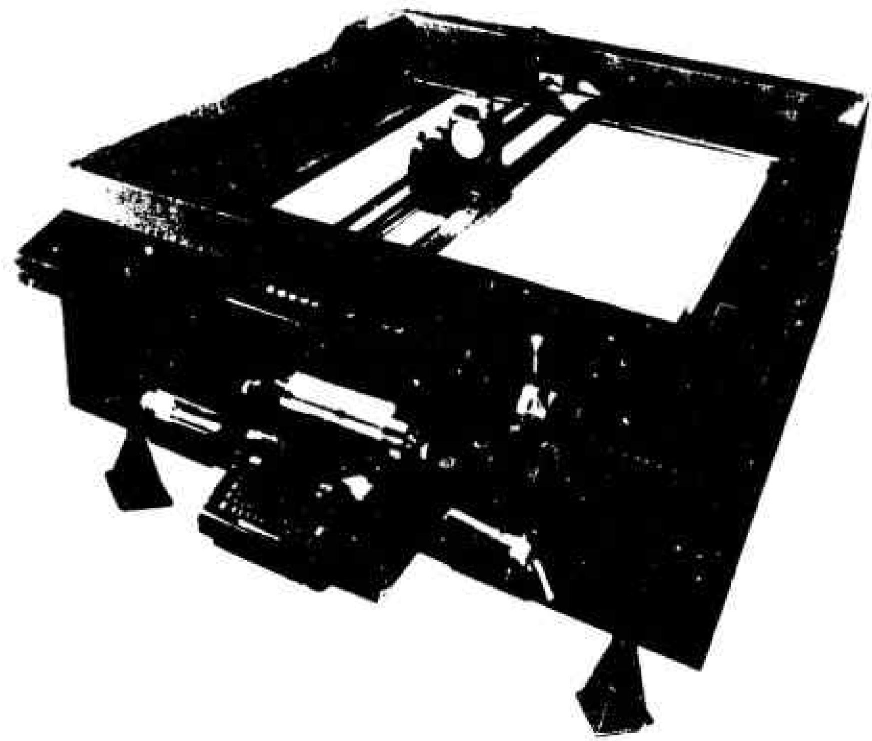

Fig. 138. Automatic Point Reading, Plotting, and Grid Ruling Machine.

This equipment was an entirely new concept in plotter design. It was one of the first plotters to use all digital logic and a new type of mechanical drive consisting of precision ball screws. With the elimination of amplifiers, servo systems, and cable or steel band drives, the inherent problems that had plagued analog plotters were eliminated.

Test and evaluation of this machine, conducted in the period from April 1961 to January 1962, concluded that it was capable of plotting and drafting with

accuracies equal to those obtained with manual coordinatographs and at a rate of speed much greater than that obtained with manual instruments. It could effect a significant saving of time and manpower when operating from manual input as well as from tape input. It was suitable for reading coordinates of points from mosaics, etc., for use in positioning systems. It was also sufficiently reliable for military use.[320]

The equipment was not service tested but it was sent to the Army Map Service where it was put into production. A complete line of modern digital plotters now used extensively in the electronic data processing industry on a worldwide basis evolved from this early development.

(4) **Planimetric Compiler.** With the development of automated systems for the production of orthophotographs, planimetric data could be compiled by direct tracing from the orthophoto image. However, experience had shown that reference to supplementary photography or old maps, as well as stereoscopic viewing of the mapping photography, was often necessary to extract and interpret the required data. Thus, a requirement developed for a device which would enable the compiler of the map to utilize this supplementary material in an effective manner.

In 1964, technical characteristics for a device called the Planimetric Compiler were prepared and a contract was negotiated with the Latady Development Company for detailed design and fabrication of an engineer design test model.

The engineer design test model delivered in June 1966 consisted of an illuminated drafting table, a stereo viewing system, and an autofocusing overhead projection unit all embodied in a single item of equipment (Fig. 139). The stereo system was capable of both normal and reversed stereo viewing at magnifications of 2X to 32X, accommodating a scale differential of up to 16X between photos of a stereo pair. The overhead projector would accommodate both opaque and transparent copy, with magnifications variable from 0.6X to 3X. Two instruments were procured, one for test of GIMRADA and one for service test at Army Map Service.

Engineer design tests of the Planimetric Compiler at GIMRADA showed that the equipment successfully met the requirements of the technical characteristics.[321] Subsequent service tests at Army Map Service revealed, however, that the equipment was too complex for quantity production use. No further development of this type of equipment was pursued.

[320] Homer C. Babcock, GIMRADA 8-TR, "Tests and Evaluation of an Automatic Point Reading, Plotting, and Grid Ruling Machine," August 1962.

[321] Gerald E. McKain, GIMRADA 35-TR, "Engineer Design Test and Evaluation of a Planimetric Compiler."

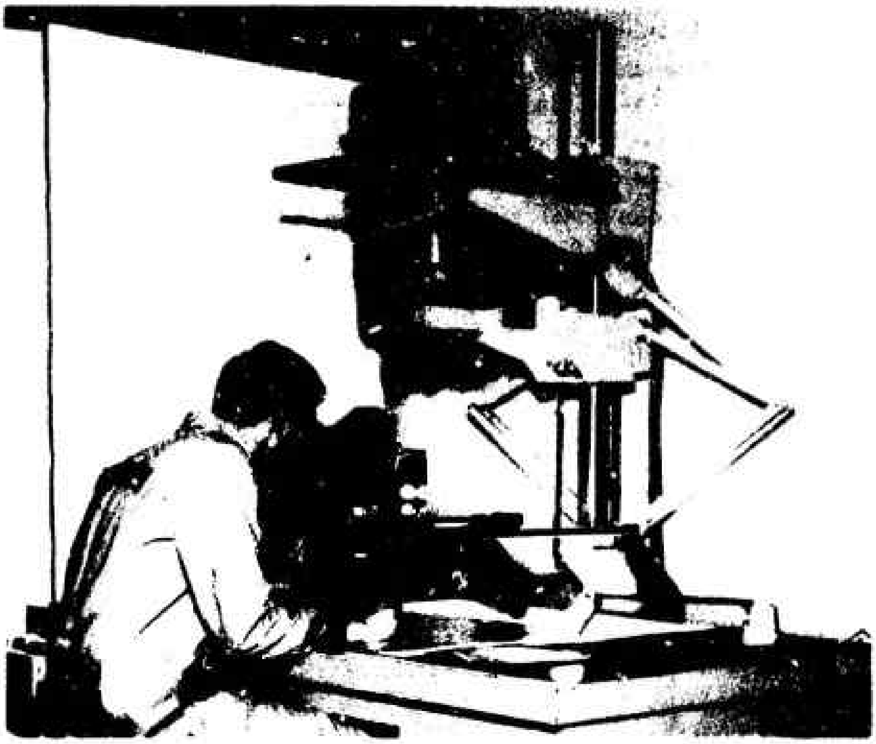

Fig. 139. Planimetric Compiler.

(5) Automatic Contour Digitizer. In the early 1960's, the Army Map Service began to receive requests from various sources for map data in digital form on magnetic tape so that it could solve map problems by electronic computers. By 1964, the Army Map Service had programmed work for the Electromagnetic Compatibility Analysis Center (ECAC) which consisted of 25 United States sheets at a scale of 1:25,000. This digital map information was essentially a reduction of height information from existing topographic maps to digital form. The Army Map Service developed techniques for producing this digitized map information by manually tracing contours and automatically recording X, Y coordinates. This data was subsequently computer processed to produce the required magnetic tapes in the required format of the user.

It was expected that ultimate user demands based on electronic data reduction equipment would require that all topographic map data be in machine readable form. Therefore, more efficient and rapid means for digitized map production were required. The problem reduced to a two-phase one: (1) reduce height information from existing topographic maps to digital form to satisfy existing and immediate requirements, and (2) perform research studies and design and develop advanced methods and equipment to satisfy emerging and future terrain data requirements that would require all topographic map data in machine readable form.

As an initial step in this direction, technical characteristics were developed and were coordinated with the Army Map Service in August 1964 for an Automatic Contour Digitizer (ACD). In January 1966, a contract was negotiated with Concord Controls, Inc., Boston, Massachusetts, to fabricate two automatic contour digitizers, one of which was to be delivered to the Army Map Service for production use, the other to GIMRADA for continued research and development. The instruments were delivered to ETL in March 1968 (Fig. 140).

Fig. 140. Automatic Contour Digitizer.

The Automatic Contour Digitizer was a computer-controlled, software-dependent system, featuring electro-optical scanning and automatic line following, data formatting and recording with means for checking the output for errors. The system controller was a Xerox Data System (XDS) 930 general-purpose computer. Inserted into the system via a drum scanner were map contour sheets of black lines on white background or a transparent film positive. The sheets were scanned sequentially in either 1- by 1-inch, 2- by 2-inch, or 4- by 4-inch sections, depending on contour density. Each section was scanned in a 400 by 400 matrix of spots by sensing reflected light as the drums rotated at 1200 rpm. Data scanned from the drums were stored in computer memory and could then be presented to the operator for interpretation, editing, and system operational control. The contour lines were automatically tracked in computer memory and, when suitably formatted and edited, the data was dumped from the computer onto magnetic tape.

During engineer tests, it was found that the basic software delivered with the system required major changes. A contract to develop a new control software system was negotiated in August 1969 with the Wolf Research Corporation. Also, major

design deficiencies noted in these tests resulted in a complete redesign of the operator's console. This was fabricated in-house.

The engineer design tests were finally completed in April 1971, and it was concluded that the ACD system could digitize contour sheets up to 24 by 30 inches.[322] One ACD with modified console was sent to TOPOCOM for service test beginning in February 1971.

During the later stages of the development of the ACD, the production center at TOPOCOM expanded its manual digital graphic recording system, and it appeared that there was no further need for work on improving the ACD. Development was terminated in 1971 because this work was being superseded by the Semi-Automatic Cartography System development.

(6) **Semi-Automatic Cartography System.** Despite advances in geodetic and photogrammetric techniques through the 1960's, the cartographic drafting process (by which the manuscript map copy is symbolized and converted into color separations required for reproduction) remained a manual, time-consuming operation. To meet the demands of future mapping concepts successfully and to benefit fully from advances in other phases of mapping, it was apparent that an automated cartographic system was required.

Based on studies made by an Army Map Service/GIMRADA Committee on Automated Cartography in 1966 and 1967, a formal development plan for a Semi-Automatic Cartographic System was completed on 1 August 1968. The objective of this development was to produce a system of hardware and computer software which would provide an improvement of at least 50 percent in production rate for standard 1:250,000 or larger scale military maps and also provide digital map data for other map-related uses. The basic concept of the cartographic automation involved digitizing the map manuscript, manipulating the data with a digital computer, and providing final output in symbolized and fine drafted format through an automatic X-Y digital plotter.

To further this development, several exploratory items were produced for test in the late 1960's and early 1970's. These included the Stereocompilation Digitizer (Fig. 141), the Digital Planimetric Compiler (Fig. 142), the Drum Scanner/Plotter (Fig. 143), and the Digital Input/Output Display Equipment (Fig. 144). Also procurement was initiated for high-precision, flatbed X-Y plotters for the system: one by the Gerber Scientific Instrument Company, Hartford, Connecticut, for in-house system development work; and the other an older model plotter, reworked by Concord Controls Inc., Boston, Massachusetts, for use in production. Both of these systems were intended

[322] J. H. Garlow, ETL-ETR-71-2, "Automatic Contour Digitizer," April 1971.

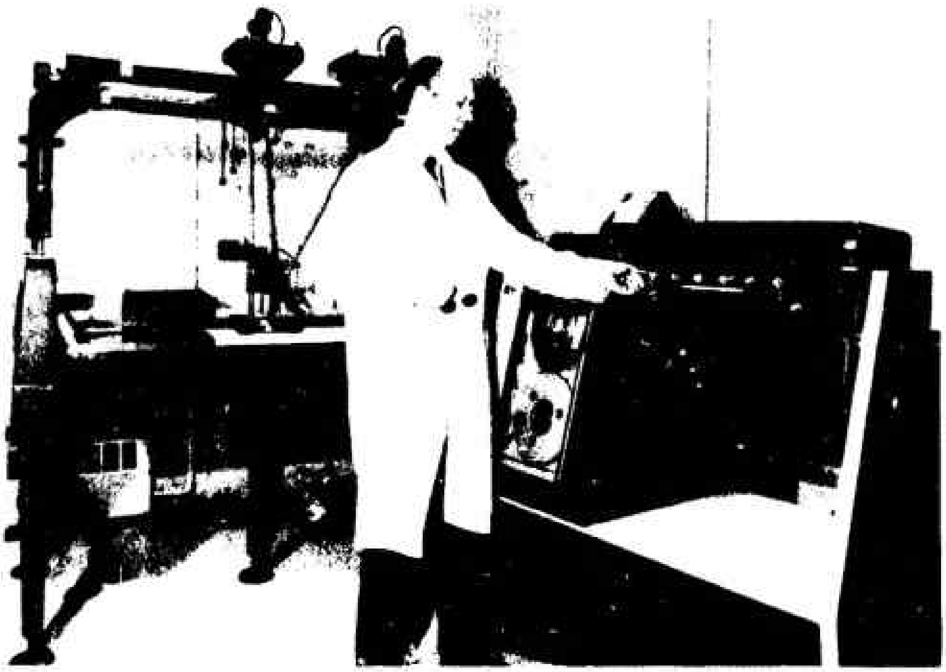

Fig. 141. Stereocompilation Digitizer.

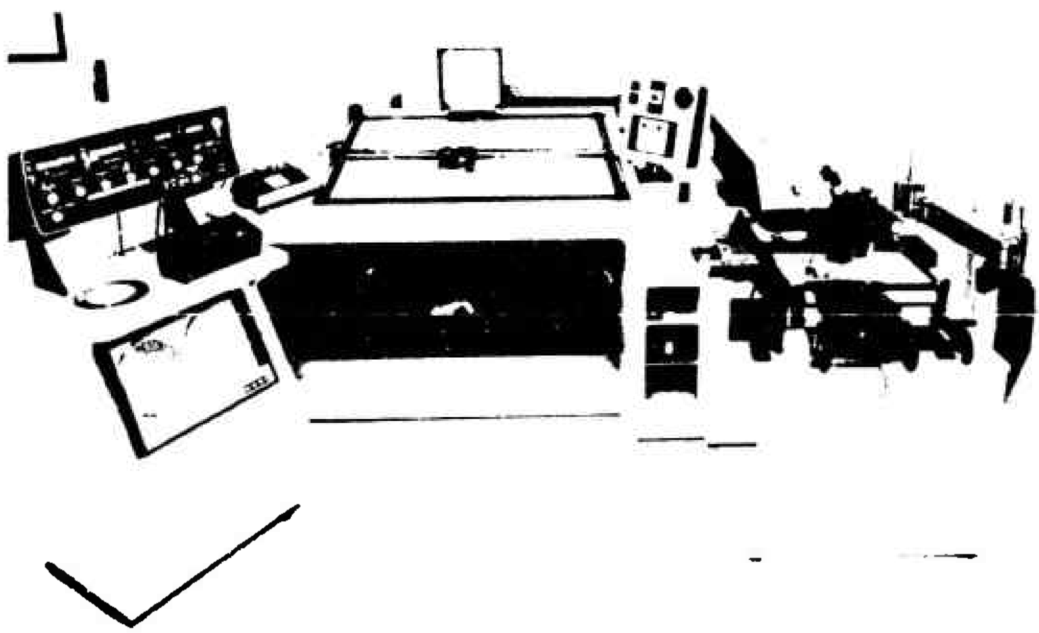

Fig. 142. Digital Planimetric Compiler

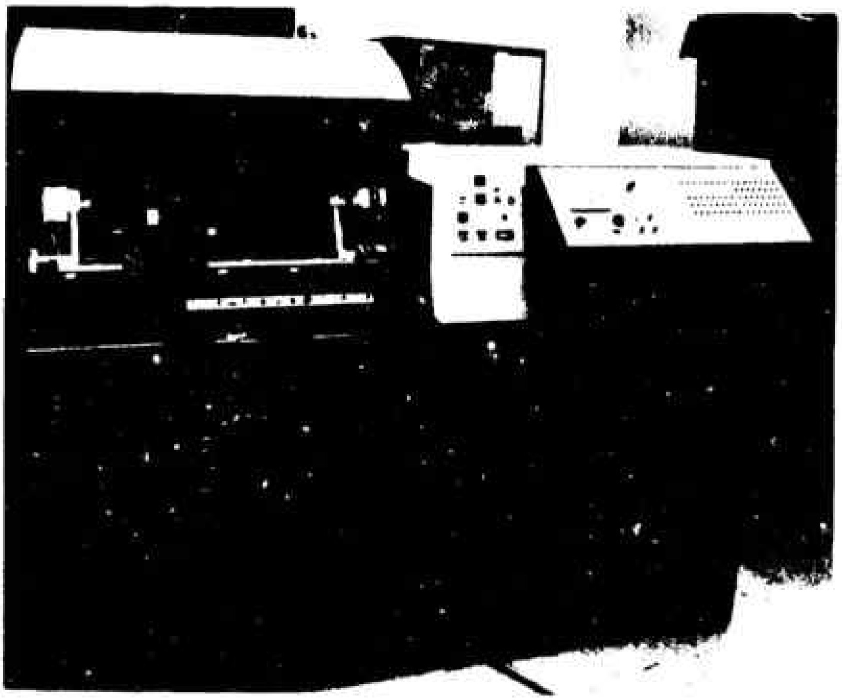

Fig. 143. Drum Scanner/Plotter.

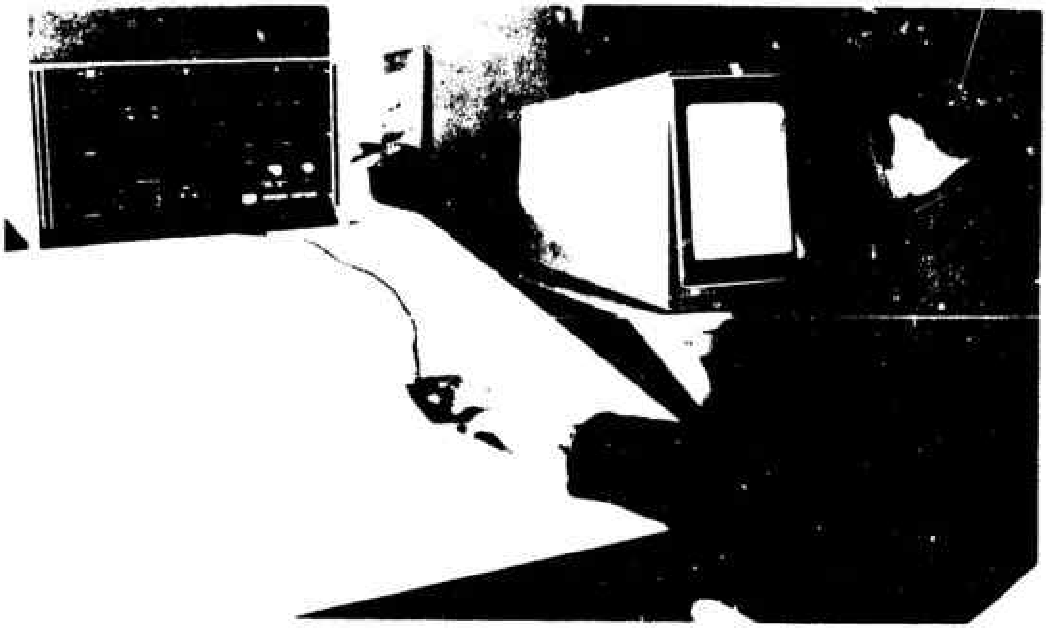

Fig. 144. Digital Input/Output Display Equipment.

primarily for drafting with a controlled light beam on film. Plans were developed for completion of the basic system and implementation in production by 1976.

(a) **Stereocompilation Digitizer.** The stereocompilation digitizer was an X-Y digitizer, with associated electronics and magnetic tape unit, designed to attach to a standard anaglyphic plotter for digitizing and recording topographic data as it is compiled. The engineer design test model was built by the H. Dell Foster Company, San Antonio, Texas, and was successfully tested in 1969. In this test, a five-color test map was produced from 17 stereo models. These were symbolized, scaled, and joined in the computer and output on a Cal Comp plotter. Due to phasing out of anaglyphic plotters from production, no further work on this item was planned. Rather, it was planned that further work in this area would involve attaching encoders to the AS-11 Stereoplotter and using the Stereocompilation Digitizer electronics and tape unit for recording data from this instrument on a test basis. If successful, the system would then be integrated into production.

(b) **Digital Planimetric Compiler.** The Digital Planimetric Compiler was also an X-Y digitizer with appropriate electronics and tape unit designed to be used over a light table for compiling planimetric data from orthophoto mosaics. The engineer design test model, built by Optomechanisms, Inc., included an H. Dell Forster Digitizer and an auxiliary stereoscope and rear projection viewer mounted on the table. Based on the engineer design tests, it was decided to disassociate the optical equipment from the digitizing equipment. The ET/ST model equipment was contracted to Dimensional Systems, Inc., Waltham, Massachusetts, with control software to be written by Information, Inc. It was to consist of a Bendix Datagrid digitizer interfaced to a minicomputer controller and tape unit. It was planned to expand this system in production so that a number of digitizers could share the minicomputer controller under software control, thus lowering the cost per digitizer.

(c) **Drum Scanner Plotter.** The Drum Scanner/Plotter, contracted to the IBM Corporation, Kingston, New York, was designed to digitize and to plot cartographic data in a raster scan mode. The device takes as input cartographic manuscripts coded in colored pencil. These are mounted on the drum and digitized by moving a photocell scanning head axially as the drum rotates. Data thus produced, after computer manipulation, is used to produce the finalized map color separation on the same equipment. Software for processing [illegible] raster data was also contracted to IBM Corporation.

(d) **Digital Input/Output Display Device.** The Digital Input/Output Display Device was designed for use in editing digital cartographic data before final plotting. It consisted of a CRT display and an X-Y digitizer on line with a control computer. With the device, the operator was presented with a graphic display of the digital

data on the CRT. He could revise the displayed data by interacting directly with the computer through the X-Y digitizer. The engineer design test system was built by Computer Displays, Inc., Boston, Massachusetts. Control software was developed in-house.

(7) **Other Cartographic and Graphic Developments of the 1960's.** Other cartographic and graphic developments of historical significance in the 1960's included the development of a Multipower Army Stereoscope in the early 1960's, the Command Retrieval Information System/Direct Input (CRIS/DI) in the mid-1960's, and the Micromap System for Display System, also in the mid-1960's.

(a) **Multipower Army Stereoscope.** The Multipower Army Stereoscope development was approved by Chief, Research and Development in July 1959, to satisfy a requirement for a versatile stereoscope to view cut stereo pairs, roll film, and roll prints (Fig. 145). The stereoscope was to be suitable for use by photo interpreters at all echelons of command where Army photo imagery interpreters may be assigned from Army levels down to and including combat commands.

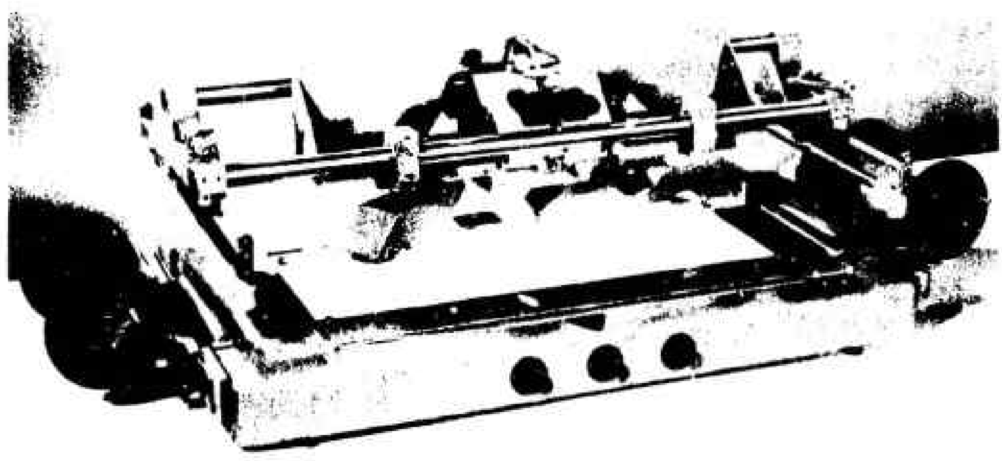

Fig. 145. Multipower Army Stereoscope.

An engineer design test model, fabricated by the Bausch and Lomb Optical Company, was actually a modified version of the AR-26 stereoscope developed by the U. S. Air Force. Modifications included the use of a zoom type optical system, providing continuously variable magnification from 2.5 to 36 power, and a cold light film illumination grid. Engineer design tests were completed in December 1962.[323] Subsequently, two additional instruments were procured for service test.

[323] Homer C. Babcock, GIMRADA 12-TR, "Engineer Design Tests and Evaluation of a Multipower Army Stereoscope," March 1963.

(b) **Command Retrieval Information System/Direct Input (CRIS/DI).** CRIS/DI was designed and built by the Amercon Division of Litton Industries. It was procured and tested by ETL to meet an Army Map Service requirement for mass storage and rapid retrieval of a large range of data as a major component in a Geodetic Control Data and Photo Record File System. It was designed to transfer standard, previously processed, 35- or 70-millimeter microfilmed images on a silver halide roll film to a Kalvar film scroll; then store, retrieve, display, and reproduce these images on Kalvar film aperture cards. This equipment was tested from April through September 1967[324] and was found to perform the storage and retrieval function as intended, but several design changes were recommended for any future procurement.

(c) **Micromap Camera for Display Systems.** The development of the Micromap Camera for Display Systems was to meet a requirement for the preparation of color microfilm transparencies (micromaps) of maps, charts, intelligence data, and similar material to be supplied by the Army Map Service or other base plant for various display subsystems and command and control systems then under development for the ADSAF concept. Considerable experience in the development of micromap equipment had been gained by GIMRADA in the early 1960's when equipment was developed to produce 70-millimeter microfilm for the Target Map Coordinate Locator and the Multicolor Electrostatic Printing Machine.

The item developed was a very versatile piece of equipment (Fig. 146). It had two copyboards, one 75 inches by 75 inches for use with opaque copy and the other 30 inches by 40 inches, trans-illuminated for use with transparent copy. The light source for the large copyboard was selected to give optimum results with color films, while the trans-illuminated board used green fluorescent tubes for maximum image resolution on black and white film. Interchangeable camera backs were provided for 35-millimeter roll film, 70-millimeter roll and cut film, 9½- by 9½-inch and 8-inch by 10-inch cut film, and a special format 70-millimeter cut film. A wide magnification range from 4:1 to 30:1 was provided.

The engineer design test model was delivered to GIMRADA on 10 March 1967. Engineer tests showed that it met all stated requirements and that it represented a major advance in the state-of-the-art in microminaturization.[325] In October 1968, the camera was transferred to TOPOCOM for high priority production work and the completion of engineer tests.

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[324] Joseph P. Goodwald, ETL 42-TR, "Engineer Test and Evaluation of the Command Retrieval Information System, Director Input (CRIS/DI)," September 1968.

[325] Erik Woods, ETL-ETR-71-5, "Micromap Camera for Display Systems," October 1971.

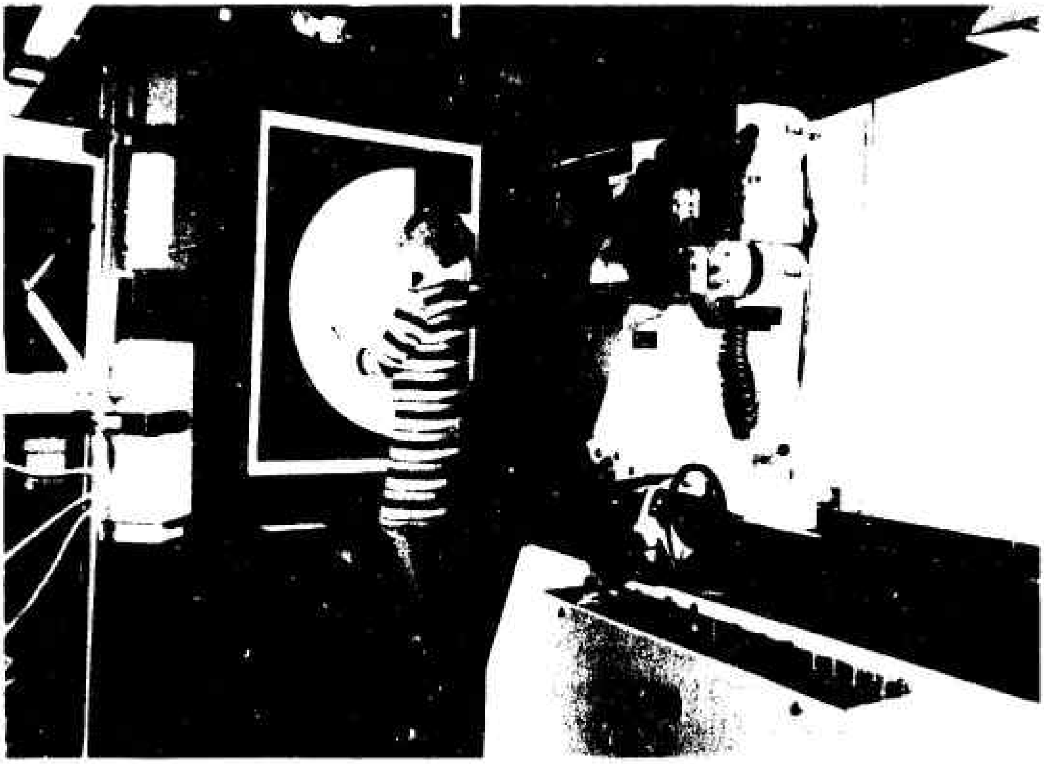

Fig. 146. Micromap Camera for Display Systems.

f. **Surveying and Geodesy.** The development program in surveying and geodesy at the beginning of the 1960's was focused primarily on the Artillery Survey System which had been demonstrated in an interim status on 4 August 1959 at Clark Mountain, Orange County, Virginia. At this demonstration, some of the components of the system were only partially developed; some were only in mockup stage. These items included the Short Range Positioning System (SREPE), Airborne Tellurometer, Automatic Position Survey Equipment, Gyro Orienter or Gyro Azimuth Theodolite, the Automatic Tracking Theodolite, and the Inertial Survey Equipment. The development of the Artillery Survey System resolved itself into programs of individual items to be developed from those components applicable in the system.

In 1960, a QMR was established for a Long Range Survey System which would provide equipment to positions at up to 24 stations within 45 minutes and in areas between 15 and 30 miles from a baseline. Work on the development of this system was destined to continue through the 1960's leading eventually to the development of the Long Range Position Determining System implemented in the late 1960's.

Early in 1962, GIMRADA was assigned the high priority project of the development of the SECOR Geodetic Satellite System. This development program continued through the remainder of the 1960's and had a major impact on the overall surveying and geodesy program in terms of allocation of personnel and financial resources.

Other significant items worked on during the 1960's included the Small North Orienting Device, All-Weather Elevation Determining System, Position and Azimuth Determining System, All-Weather Angle Measuring System, Distance and Azimuth Determining System, and the Doppler Translocation Field Equipment.

Most of these programs represented highly sophisticated and advanced approaches to the age old problem of surveying. These advances were made possible by technological advances in computer science, inertial navigation systems, electronic ranging, and navigation and related areas. Through exploitation of these advanced technologies, radical departures from the old transit and tape approach to surveying were made possible.

(1) **Astronomic Survey Equipment (60° Pendulum Astrolabe with Electronic Transit Detector) (Automatic Position Survey Equipment).** As noted previously, the development of the Automatic Position Survey Equipment, a component of the Artillery Survey System, started in 1956. In June 1957, a contract was awarded to General Mills, Inc., for the design, fabrication, and test of a system of equipments that would automatically determine an astronomic position. Such equipment was developed and was delivered to ERDL in July 1959. Testing indicated satisfactory operation, proving the feasibility of automating the complex operations of astronomic surveying; but the practicability of the system was questionable because of the complexity of the equipment and the maintenance problems associated with this complexity. Therefore, a second contract was awarded to General Mills to modify the equipment to provide a semi-automatic mode of operation, thereby simplifying the system. This system was tested in the Spring of 1961, and the test results indicated a reliable second-order capability.

Upon completion of these tests, service test procurement was implemented and quotations were obtained from industry for this procurement. But before the award of a service test procurement contract, a conference was held at GIMRADA on 22 August 1961 to review the requirements for the automatic Positioning Survey Equipment, requirements for astronomic surveying equipment, to determine the suitability of equipment sets in the system and recent developments in the field of astrosurveying equipment and to determine the need for improvement of existing equipment.

At this conference, it was concluded that the requirement for the Automatic Position Survey Equipment was no longer valid and, therefore, GIMRADA

should stop all work on the APSE and re-orient the effort toward the modernization of the astro position sets of equipment in the system including a redesign of the astrolabe then provided in the set.

The Automatic Position Survey Equipment Program, therefore, resolved itself into updating and revising astro equipment sets, with the required product improvement to accomplish this updating.

In FY 62, a contract was awarded to Perkin-Elmer Corporation, Norwalk, Connecticut, for the development of an improved astrolabe with electronic transit detector (Fig. 147). In 1963, development contracts were awarded to McKiernan-Terry Corporation for an electronic chronometer and to Century Electronics for a new data recorder. Also, the final design and modifications for a time signal receiver were procured from General Mills, and the preparation of programs for the FADAC computer was initiated.

Fig. 147. Astrolabe—60° Pendulum with electronic transit detector.

All components were delivered in April 1963, and engineer design tests were initiated. It was intended that after engineer design tests, engineer and service tests would be conducted by USATECOM. However, in December 1963, the engineer

and service test phases of the program were eliminated by Army Materiel Command because the Combat Development Objective Guide paragraph that supported the p. gram had been cancelled. However, product improvement tests were conducted. USATECOM assigned personnel from the U. S. Army Armor Board, Fort Knox, Kentucky, to assist in these tests.

As a result of these tests,[326] it was determined that the 60° pendulum Astrolabe with Electronic Transit Detector did not improve accuracy. Since it was more costly than the 60° pendulum astrolabes without ETD, it was not suitable for the astro-surveying sets. Satisfactory results were obtained with the other improved items, except for the data recorder which required modification. The final result of this program, initially intended to provide automatic position survey equipment was a revised equipment set list.

(2) Short Range Electronic Positioning Equipment (SREPE). The SREPE was one of the interim equipments under development in the late 1950's which was also included in the Artillery Survey System as demonstrated in August 1959 (Fig. 148). The primary objective of the development of this equipment was to provide an all-weather, day-night, highly portable system for determining survey positions specifically for use by artillery units operating within the 10- by 10-mile area concept of the Artillery Survey System. The requirement for a rapid means of determining positions over short ranges was placed on the Topographic Engineering Department, ERDL, in May 1958.

When it was learned that the National Telecommunications Laboratories (NTL) of Johannesburg, South Africa, had designed a highly portable system (Terrafix), a so-called hyperbolic, position-fixing system with the required lane identification feature, negotiations were initiated with the South Africans to develop and build a compact, transistorized version of Terrafix called the SREPE.

In November 1958, a contract for a prototype SREPE was awarded to Tellurometer (PTY) Ltd., Capetown, South Africa, since this firm had been designated by the National Telecommunications Laboratories to fabricate the hardware and market the system. This model was delivered to ERDL in July 1959 in time for the Artillery Survey System demonstration in August 1959.

In December 1958, a contract was awarded to Tellurometer (PTY) Ltd, Plumstead, CP Union of South Africa, for a portable SREPE. This transistorized equipment was delivered to GIMRADA on 13 February 1961. After 3 weeks of testing

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[326] Peter J. Cervarich, GIMRADA 28-TR, "Product Improvement Test Report of Astronomic Surveying Equipment," March 1966.

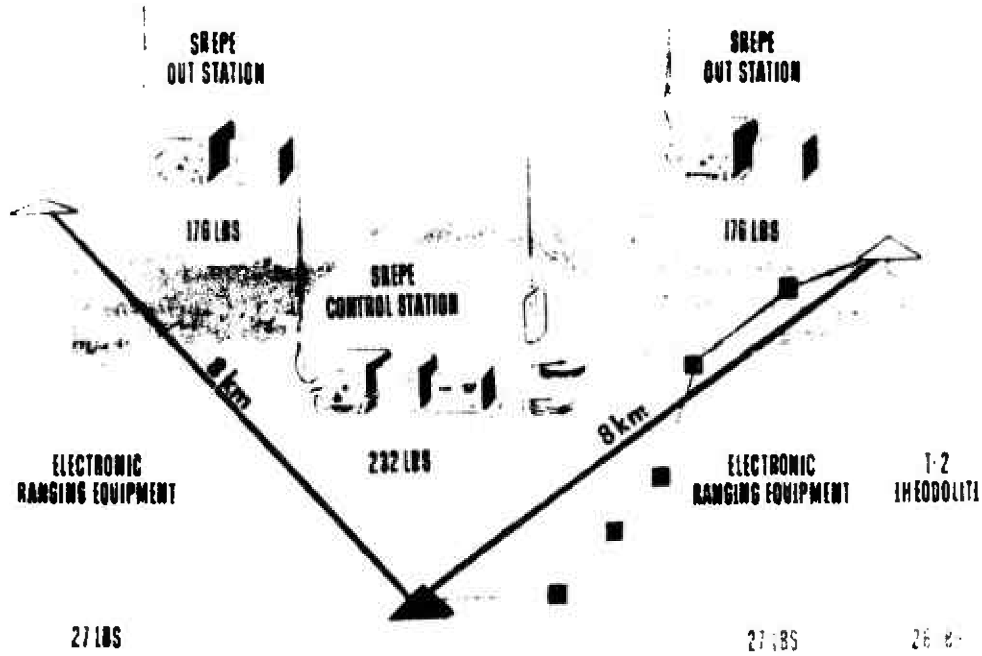

Fig. 148. Short Range Electronic Positioning Equipment (SREPE), conceptual schematic.

in Northern Virginia, the equipment had to be returned to the contractor for modification because of excessive breakdowns and delays due to design flaws in circuitry and components. The modified equipment was returned to GIMRADA on 1 September 1961, and although some test data was obtained in late 1961 and early 1962, the equipment again had to be returned to the contractor because of equipment failures. It was replaced with a new model designated the service test model in September 1962.

The SREPE consisted of a basic control station with transmitter and synchronizing receiver and two outstation transmitters, plus any number of mobile receivers. A small analogue plotter was provided to plot the hyperbolic coordinates at the mobile receiver onto a UTM grid or other coordinate grid system as desired. Computer programs were also prepared by the FADAC computer. In operation the control station transmitter and outstation transmitters were located in known positions; the mobile receiver, any number of which could be operated simultaneously, was positioned on the unknown point for which position was desired.

After engineer test of the second, or service test, model SREPE at GIMRADA, it was delivered to Fort Sill, Oklahoma, for service tests in November 1962.

At the completion of engineer tests,[327] it was concluded that the SREPE did meet the accuracy requirements for position determination within the 45-minute time limitation for the 10- by 10-mile area concept of the Artillery Survey System (radial error of 15 meters), but it was not sufficiently accurate for geodetic survey applications. It was further concluded that the equipment was suitable for service test.

(3) **Airborne Tellurometer.** Another item included in the Artillery Survey System demonstration of August 1959 was the Airborne Tellurometer. The development of this item had been contracted to Tellurometer (PTY) Ltd., Capetown, South Africa, in March 1958. The equipment was delivered in the U.S. in July 1959, in time for the August demonstration.

The airborne tellurometer equipment (Fig. 149) consisted of a master station mounted in an aircraft and three physically identical remote stations for mounting on selected ground points. The equipment measured the slant range from the airborne master station to each of the remote stations by phase-comparison techniques, providing data which with appropriate correction for aircraft altitude and atmospheric propagation effects provided the geodetic distance from aircraft position to each remote station position. The data was continuously recorded in the aircraft. Thus, operating with two known ground stations and one unknown station, the position of the unknown station could be computed by trilateration. Or, by line crossing techniques with a remote station at each end of the line, the distance between the end points could be determined.

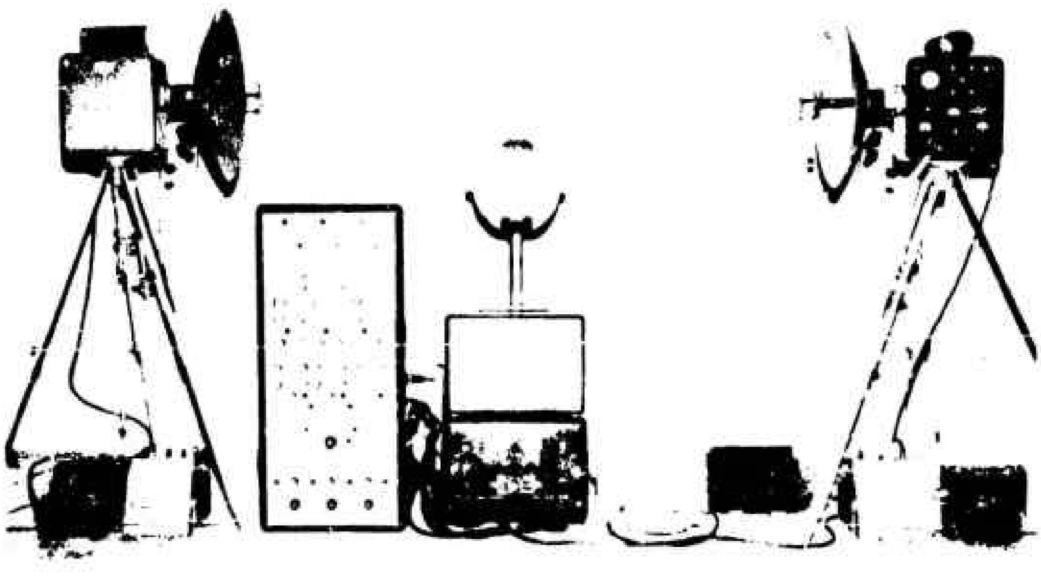

Fig. 149. Airborne Tellurometer: ground and air station equipment.

[327] George P. Schreiber, Jr., GIMRADA 9-TR, "Engineering Test Report: Short Range Electronic Positioning Equipment (SREPE)," January 1963.

Engineer testing of this equipment[328] in late 1959 and early 1960 was handicapped by inclement weather and equipment malfunction. Although the tests did not reflect the predicted accuracy or repeatability of the system, they did indicate the feasibility of an airborne ranging system for survey operations.

In June 1960, the contract with Tellurometer, Inc., was modified to include the fabrication of a much lighter, field worthy system and to increase the reliability of all items. It is interesting to note that, at the same time, a contract was awarded to the Cubic Corporation, San Diego, California, for a feasibility study of a more sophisticated automated Long Range Survey System using airborne ranging equipment.

The modified Airborne Tellurometer Equipment was delivered to GIMRADA on 29 June 1961, and combined pre-acceptance and engineering tests were started immediately. Field tests were conducted in the Northern Virginia area from July to September 1961.[329] These tests were also handicapped by inclement weather and equipment malfunction, but a limited amount of test data was obtained. It was concluded that the system could meet an accuracy of ±1 meter per ±1 part in 100,000 and could extend control between non-line-of-sight points with less expenditure of time and personnel than ground survey equipment.

At this point, further work on the development of the Airborne Tellurometer System was suspended in favor of work on the more sophisticated Long Range Survey System -- a system which was designed to conform to user requirements not only for position accuracy but also for time of survey of a large number of widely dispersed points.

(4) **Long Range Survey System.** In the same month that the Qualitative Materiel Requirement (QMR) for the Long Range Survey System was approved, June 1960, a contract was awarded to the Cubic Corporation, San Diego, California, for a feasibility study[330] of an electronic positioning system utilizing spread spectrum ranging techniques to satisfy the requirements. The overall objective was to provide artillery and topographic mapping units with improved survey methods for mapping and fire control at increased speed, under all-weather, all-terrain, day-night field conditions, incorporating nondetectable, nonjammable techniques. Specifically, the survey system to be developed was to have the capability of positioning at least 24 stations within 45 minutes in areas between 15 and 350 miles from a baseline and transmit forward observer data, such as range and azimuth to target, back to the base station.

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[328] John G. Armistead, "ERDL Draft Engineering Test Report Airborne Tellurometer," March 1960.

[329] Thomas F. Treadway, GIMRADA Draft Engineering Test Report, "Airborne Tellurometer," October 1961.

[330] "Long Range Survey System," Interim Report, Cubic Corporation, San Diego, California, November 1960.

In March 1961, a contract was awarded to the Cubic Corporation to design and fabricate an engineer design model of the Long Range Survey System (Fig. 150). The system developed for test consisted of a master or control station mounted in a 2½-ton vehicle, a two- or three-man portable base station, an airborne relay station, and up to 25 portable positioning equipments to be located at points for which positions are desired. The positioning equipments were identical to the base stations in all respects except for their use within the system. In operation, the locations of the positioning equipments were determined with respect to the base stations which were located over known control points. All ranging signals were relayed through the airborne transponder to the unknown points as required to extend the line-of-sight ranging capability up to 275 kilometers from the aircraft. All system elements could automatically transmit data along with the ranging signal. All transmissions were made difficult to detect and resistant to jamming by using spread spectrum techniques. All range and related data received at the master station was fed directly to the FADAC computer and was processed and printed out on a teletypewriter.[331]

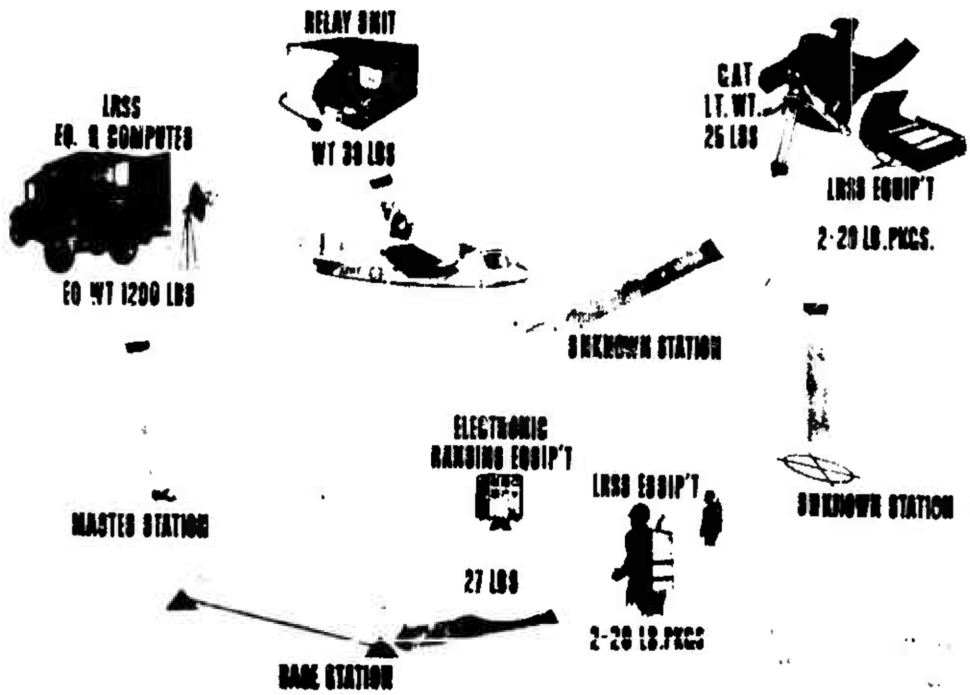

Fig. 150. Long range survey system concept.

Engineer design tests were completed in August 1963. During these tests, questions arose as to the soundness of this system approach, particularly with

331 "Long Range Survey Systems (U)," Final Report, Volumes I and II, Cubic Corporation, December 1963 CONFIDENTIAL.

respect to detectability and jam resistance, but also with respect to system reliability and operation. Therefore, a special investigating team was appointed by GIMRADA on 31 July 1963 to make a technical analysis of the system's basic concept and design. This team was headed by the Technical Advisor of GIMRADA and included experts both from within and outside of the GIMRADA organization. The team concluded that the basic concept of the system was sound, but there there were some critical problem areas to be resolved to provide a satisfactory service test system. These problem areas include jam resistance, minimum time on the air, false lock, command and message channel limitations, lack of voice communications, and lack of automatic plot of aircraft position, height determination capability, and reliability. The team recommended that the transmitter power output of the service test system be increased to improve jam resistance and redesign to correct the other problem areas.

In November 1963, an In-Process Review approved the development of an Engineer/Service Test System with slightly modified military characteristics: i.e., increased weight allowance for the positioning equipment, reduced system reliability requirements, and reduced accuracy requirements for position and elevation. In June 1964, a fixed-price contract was awarded to the Cubic Corporation for the design and fabrication of the Engineer/Service Test System.[332]

During in-plant and field evaluation of this system, many deficiencies were uncovered. The combined effect of these deficiencies and the operational reliability of the system were such that continuation of engineer/service test of the system was not possible and prevented completion of the acceptance test program. Again, GIMRADA appointed an evaluation team in July 1966 to obtain additional technical data to determine the feasibility of continued development of the Long Range Survey System. The team membership was augmented 4 October 1966 by the appointment of two members from the U. S. Army Electronics Command.

The Evaluation Team report[333] again concluded that the overall system concept was sound and that the system potential was high. However, it pointed out specific hardware and operational changes which must be made before the system potential could be realized. The report recommended that a portion of the Long Range Survey System equipment be modified as specified and subjected to a user evaluation with procurement of additional systems or components deferred pending this user analysis.

After considerable delay, a special in-process review was held in April 1967 to determine the proper course of action with respect to the Long Range

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332 "Long Range Survey System (U)," Interim Report, Cubic Corporation, San Diego, California, November 1964, CONFIDENTIAL.

333 John G. Armistead and Others, GIMRADA Special Report, "Investigation and Evaluation of Long Range Survey System Lightweight," November 1966.

Survey System. At this review, it was decided to terminate the contract with the Cubic Corporation and to plan a new approach to solve this problem. The Combat Developments Command was directed to update the QMR, and ETL was directed to prepare a program for a follow-on system. The Cubic Corporation contract was finally terminated in March 1968. The development of the Long Range Survey System, for which such high hopes had been held over the years, was ended in favor of a more advanced approach.

(5) **Long Range Position Determination System (LRPDS).** Following the demise of the Long Range Survey System, an updated QMR was approved in March 1967, and a program plan was approved in May 1968 to develop a follow-on system named the Long Range Position Determination System (LRPDS). A study of the LRPDS was made under contract by Communications and Systems, Inc., in 1969.[334]

The configuration of this system is similar to the Long Range Survey System in that it consists of a truck-mounted control, calibration, and maintenance station, a transponder in an aircraft, and up to 30-man portable transponders (Figs. 151, 152, and 153). It differs significantly and fundamentally from the Long Range Survey System in its basic method of position determination. Whereas the Long Range Survey System was based on a ranging and trilateration approach to position determination, the LRPDS is based on a range-change method. This approach offers many advantages over the direct-ranging approach, therefore, it is anticipated that it will provide a solution to many of the problems encountered with the Long Range Survey System.

A contract for the design and fabrication of engineer/service test hardware of the LRPDS was awarded to Motorola, Inc., Government Electronics Division, Scottsdale, Arizona, in FY 70 with equipment delivery for test scheduled for the later part of calendar year 1972.

(6) **Elevation Determining System.** The problem of the rapid determination of elevation or difference of elevation over a large area with accuracies suitable for fire control and mapping in support of artillery, missile, and mapping units was a longstanding one in the early 1960's. Over the years, several studies had been made to determine the best approach to a solution to this problem, but these studies failed to provide a solution for both speed and accuracy.

In the late 1950's, the U. S. Geological Survey had been using a device known as the Johnson Elevation Meter to determine elevation for picture point controls and other mapping applications; this application had been followed with interest by the Topographic Division, ERDL, with the intent of possible development for military

334. "Study of the Long Range Position Determination System (U)." Communications and Systems Inc., Falls Church, Virginia, Interim Report: October 1969, Final Report: January 1970, CONFIDENTIAL.

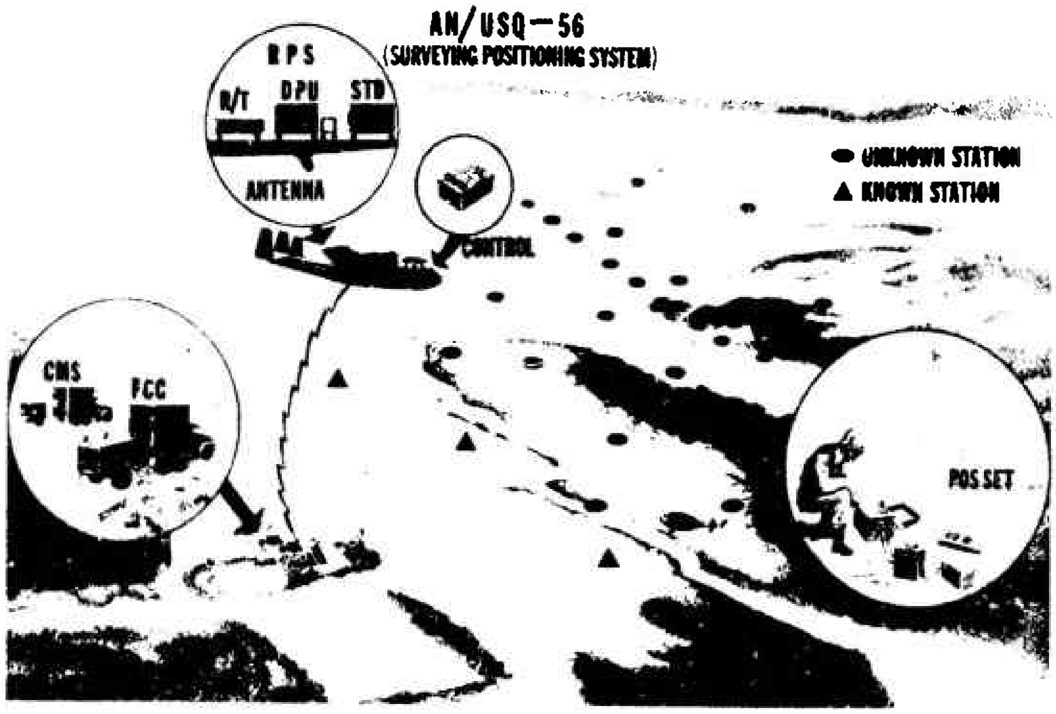

Fig. 151. Long Range Position Determination Concept.

Fig. 152. Long Range Position Determination System: Control Station.

Fig. 153. Long Range Position Determination System: Positioning Set.

use. Since a rapid means of elevation determination was a part of the overall Artillery Survey System requirement, it was decided in 1960 to procure a transistorized Johnson Elevation Meter for test. A contract for this item, subsequently called the Ground Elevation Meter, was awarded to the Sperry-Sun Well Surveying Company, Houston, Texas. The Ground Elevation Meter was delivered to GIMRADA on 4 April 1961 and was tested in Northern Virginia in April and May 1961.[335]

The Ground Elevation Meter was a four-wheel drive, four-wheel-steer vehicle equipped with a fifth wheel for measuring distance travelled and a pendulum for measuring slope. The distance and slope information was fed automatically to an electronic computer which integrated the information to provide ground elevations.

The tests of this equipment demonstrated that it was capable of meeting the ±5-meter accuracy requirement of the Artillery Survey System, but it was

[335]Duane C. Bright, GIMRADA 5-TB, Engineering Test Report: "Elevation Meter, Ground," March 1962

not capable of meeting the 45-minute time limitation for establishing elevations in a 40- by 40-mile area. It was demonstrated that it could provide elevations at speeds up to 40 miles per hour on hard surfaced and improved roads with an accuracy of 1 foot times the square root of the distance traveled with closure adjustment; and without closure adjustment, with an accuracy of ±4 feet per 10 miles.

Further work on the ground elevation meter was suspended at this point since there was no user interest (curiously, not even in the Army Map Service) in the application of the system, and the rapid determination of elevations remained one of the unsolved problems associated with field artillery survey operations.

In March 1965, a Qualitative Materiel Development Objective was approved for a man-portable device to determine rapidly the elevation of points with respect to sea level (Fig. 154). Significant material objectives of this requirement were a weight of 10 pounds and an accuracy of 10 feet in a time frame of 10 minutes. It was visualized that this would be a small self-contained device invulnerable to electronics counter measures and that it would be applicable for long-range patrols as well as for use with the Long Range Position Determining System. It would be organic to all field artillery survey parties as well as to some engineer units to replace trigonometrics leveling and barometric altimetry. In spite of several exploratory efforts to find a technical approach to meeting these requirements, no feasible solution has been found.

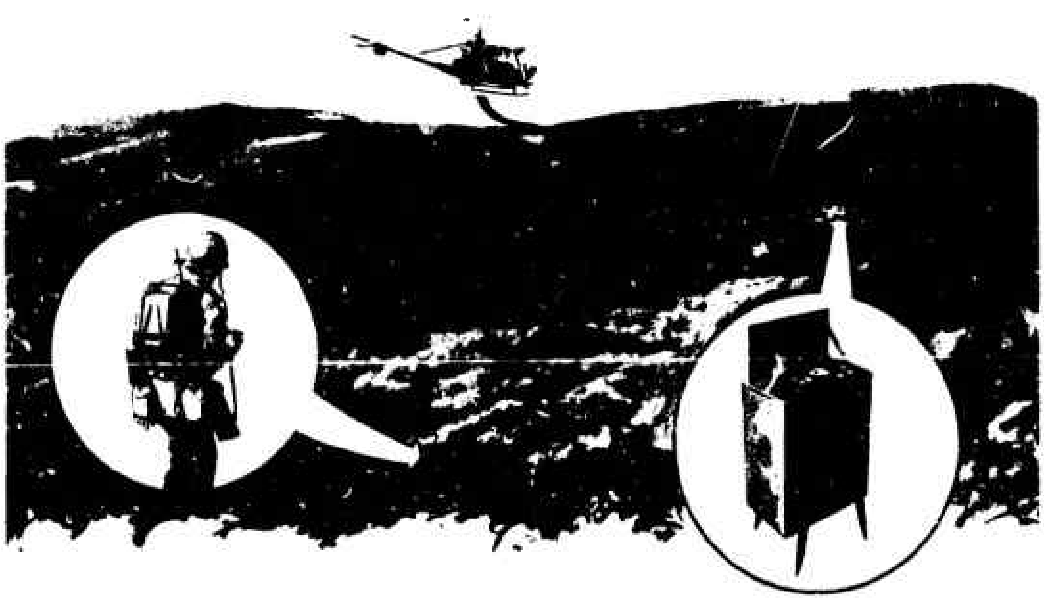

Fig. 154. Height Determining Device, Lightweight.

(7) **Inertial Survey Equipment (ISE).** The exploratory development of the inertial survey equipment was started in the late 1950's as an approach which could potentially meet all of the requirements of the Artillery Survey System. These requirements at that time called for methods and equipment which would establish in 45 minutes, 12 to 14 survey control stations in a division area to an accuracy of 1:3,000 with respect to survey control together with elevation accuracy to ±5 meters and azimuth accuracy to ±20 seconds of arc. Of all the approaches investigated up to that time, including techniques such as flare triangulation, electronic hyperbolic systems, and simultaneous electronic ranging to an airborne station, only the inertial technique appeared potentially capable of meeting the full requirements.

In June 1959, a contract was awarded to General Electric Company for a study and preliminary design of an inertial system suitable for artillery surveys. The study, completed in September 1959, concluded that an inertial system employing data correction techniques theoretically was capable of performing the artillery surveys. In January 1960, a contract was awarded to General Electric for the final design and fabrication of prototype equipment.

Initially, the system concept was based upon a traverse closure technique requiring the use of a separate, general-purpose computer. Position readout was to have been in terms of geographic coordinates to simplify computer requirements. In July 1960, however, the user requested that the system design be changed to permit enroute data correction (open traverse survey) and position readout in Universal Transverse Mercator (UTM) grid coordinates. This change was incorporated in the system design. The prototype system (Fig. 155) designed for use in either a ground vehicle or a helicopter was not completed for system test until December 1962. It was tested by General Electric project personnel at Philadelphia and Valley Forge, Pennsylvania, and Burlington, Vermont, under the monitorship of GIMRADA during December 1962 to April 1963. The system was delivered to GIMRADA on 16 April 1963.[336]

The test of the prototype system demonstrated that it was feasible to perform surveys of 1-hour duration to an enroute accuracy of about 25 meters mean radial distance but that the prototype was not suitable for engineering tests because of sensitivity of the computer subsystem to vibration and shock under dynamic conditions.[337]

On 24 April 1963, an in-process review was held to determine the direction of future development effort in the use of inertial techniques for surveying. At this review, GIMRADA was directed to terminate, by 30 June 1963, the task on inertial

[336] "Inertial Survey Equipment (GEISHA)," Final Report, General Electric Co., Burlington, Vermont, May 1963.

[337] Robert T. Flowe, GIMRADA 16-TR, Engineering Design Test Report: "Inertial Survey Equipment (ISE)," October 1963.

Fig. 155. Inertial Surveying Equipment—Engineering Design Model.

survey equipment pending the approval of a QMR and military characteristics by Combat Developments Command. Thus ended, for the time being, the development of the inertial techniques approach to the solution of the artillery survey problem. Work was resumed, however, with the implementation of further studies on the application of inertial techniques to surveying in 1965. These studies finally led to the implementation of the development program for the Position and Azimuth Determining System (PADS).

(8) Position and Azimuth Determining System (PADS). Although the development of the inertial survey equipment had been terminated in June 1963 pending the approval of a QMR by Combat Development Command, interest remained high in the application of these techniques for artillery survey because of the potential for meeting the total requirement for these surveys, horizontal position, elevation, and azimuth. Therefore, in November 1965, a contract was awarded to the Guidance and Control Division, Litton Systems Inc., to study the application of inertial techniques to surveying (Fig. 156). These studies, aimed at a feasible approach for performing artillery surveys of 6 hours duration at latitudes as high as 75°, determined that while a pure inertial system would not meet all the goals, with such aids as a Laser Velocimeter and continuous Kalman filtering using high grade inertial gyros and accelerometers, a vehicle-mounted system would be feasible.[338]

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[338]"Application of Inertial Techniques to Surveying," Final Report, Litton Systems, Inc., Guidance and Control Systems Division, Woodland Hills, California, November 1966.

TRUCK MODE CONCEPT

DESIGN GOALS

POSITION - 20 METERS CEP
ELEVATION - 10 METERS RMS
AZIMUTH - 0.3 MIL RMS
SYSTEM REACTION - 15 MINUTES
MISSION TIME - 6 HOURS
OPERATION - DAY/NIGHT & ALL - WEATHER
AREA OF OPERATION - 75° N TO 75° S LAT.
SECURITY - SELF-CONTAINED & NON JAMMABLE

Fig. 156. Position and Azimuth Determining System (PADS): concept and goals.

From December 1967 to June 1968, additional studies were made under contract by Litton Systems to establish a higher level of confidence in the feasibility and practicability of the land configuration of the Position and Azimuth Determining System through inertial instrument testing, systems simulation, and Laser Velocimeter analysis and test.[339] These studies were further supplemented by studies in 1969 aimed at selecting the better of two possible configurations for the system.[340]

The basic system proposed as a result of these studies included an inertial platform to provide the coordinate reference frame and to measure the vehicle acceleration. A Laser Velocimeter was to bound the inertial velocity error and provide vertical velocity measurements. Calculations to determine present position and azimuth from the measured data provided by the inertial platform and the Laser Velocimeter were to be performed in the computer which was also to update the system parameters during the mission through the use of Kalman filter techniques. The azimuth transfer device was to be a conventional theodolite affixed to the inertial platform.

A contract was awarded to Litton Systems, Inc., on 3 February 1971 for one experimental truck-mounted system. Delivery of the equipment was scheduled late in 1972.

[339] "Advanced Study of a Position and Azimuth Determining System," Final Report, Litton Systems, Inc., Woodland Hills, California, December 1968.

[340] "Advanced Study of a Position and Azimuth Determining System," Supplement to Final Report, Litton Systems, Inc., Woodland Hills, California, September 1969.

(9) **Lightweight Gyro Azimuth Theodolite.** The origin of active work by ETL directed toward the development of equipment using gyroscopic devices for surveying can be traced to the 1956 to 1957 period when investigations were initiated under a task on inertial surveying equipment. During the course of initial investigations, it was found that German scientists had demonstrated the feasibility of achieving survey accuracy with gyroscopic instruments as early as 1921, although the equipment at that time was not suitable for field use. The indications were that gyro equipment which would provide a gyroscopic azimuth of sufficient accuracy and in sufficiently short time to be applicable to artillery surveying and weapons orientation could be developed for field use.

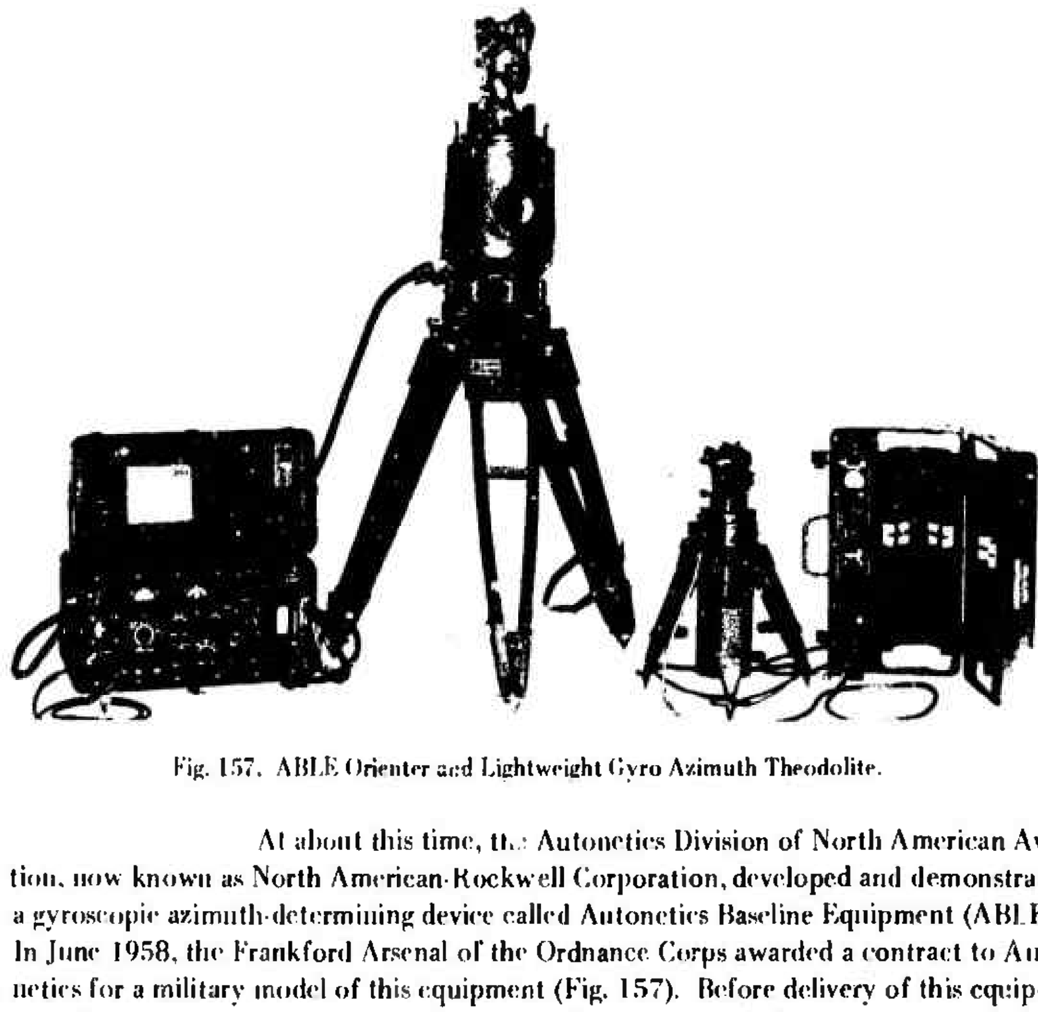


Fig. 157. ABLE Orienter and Lightweight Gyro Azimuth Theodolite.

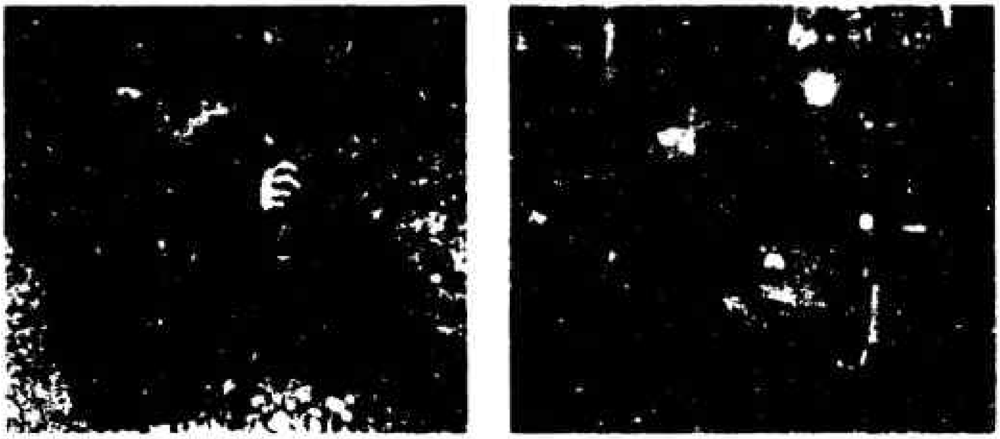
At about this time, the Autonetics Division of North American Aviation, now known as North American-Rockwell Corporation, developed and demonstrated a gyroscopic azimuth-determining device called Autonetics Baseline Equipment (ABLE). In June 1958, the Frankford Arsenal of the Ordnance Corps awarded a contract to Autonetics for a military model of this equipment (Fig. 157). Before delivery of this equipment by Autonetics, the responsibility for the development of all gyroscopic orientation devices except those involved in the Pershing missile was assigned to the Corps of Engineers. The contract for the ABLE was transferred to ERDL, and the test equipment was

delivered there in November 1958. With only limited engineer tests at Fort Belvoir and limited service test by the Artillery Board at Fort Sill, Oklahoma, it was determined that the ABLE satisfied an urgent requirement for such a device. It was type classified under the title "Surveying Instrument: Azimuth Gyro, Artillery" in October 1959. This equipment weighed approximately 200 pounds and gave an accuracy of 30 seconds (1 sigma) at 35° latitude and 1 minute (1 sigma) at 65° latitude.

In 1960, based on the need for a lightweight device for azimuth determination as a subsystem of the Long Range Survey System, a contract was negotiated with Lear Siegler, Inc., Astronics Division, for the study, design, and prototype model fabrication of a Lightweight Gyro Azimuth Theodolite with an accuracy capability suitable for the LRSS.

The Lear Siegler instrument was delivered to GIMRADA in March 1962 for engineer design tests (Fig. 158). In the meantime, the Autonetics Division of North American Rockwell Corporation undertook a company-funded development based on the lightweight Gyro Azimuth Theodolite requirements and delivered to GIMRADA in July 1961 a Miniaturized Autonetics Baseline Equipment (MABLE) (Fig. 159). Engineer test of the MABLE showed that it met the objectives and the military characteristics for artillery use and could be suitable for field use with correction of deficiencies. It was sent to the U. S. Army Artillery Board at Fort Sill, Oklahoma, for service test.

Fig. 158. Gyro Azimuth Theodolite–Lightweight: Lear experimental model.



Autonetics Lear

Fig. 159. Gyro Azimuth Theodolite, Lightweight–Autonetics and Lear models.

The test instrument delivered by the Astronics Division of Lear Siegler, Inc., in March 1962 consisted of a theodolite mounted on a gyroscopic reference unit, a combined electronic control unit and carrying case, and a tripod. It was powered by internal batteries and weighed 31 pounds, 6 ounces. After 20 minutes operation time, it gave azimuth accuracies of 0.38 mil (standard duration). It was concluded as a result of engineering tests[341] that it met the requirements for short-range weapons orientation and, on correction of some minor deficiencies, it would be suitable for field use.

In June 1963, a fixed-price contract was awarded to Lear Siegler for three engineer/expanded service test models correcting the deficiencies noted in the prototype model tests. One of these instruments was delivered to GIMRADA in August 1964 for compatibility tests with an instrument shelter which had been developed in-house to permit accurate instrument operation in high winds. In March 1965, two instruments were delivered to Aberdeen Proving Ground, Maryland, for engineer test and one was delivered to the Artillery Board at Fort Sill, Oklahoma.[342] At about the same time, two instruments built by the Astro Space Company with its own funds were submitted for test. One each was sent to the Aberdeen Proving Ground and Fort Sill for concurrent testing with the Lear Siegler instrument.

It was not until 25 March 1965 that a QMR for this development, which was initiated in 1962, was approved by the Combat Development Command,

[341] Robert T. Flowe and Duane C. Bright, GIMRADA 11-TR Engineering Test Report: "Lightweight Gyro Azimuth Theodolite (LEAR North Seeking Gyro Model No. 11NG530A)," February 1963.

[342] George N. Clausen and Robert T. Flowe, GIMRADA 23-TR, "Research and Development Acceptance Test Report Surveying Instruments (Azimuth, Gyro, Lightweight/Lear Siegler Inc. Models)," July 1965.
"Lightweight North-Seeking Gyro Azimuth Surveying Instrument," Final Report, Lear Siegler, Inc., June 1965.

providing the needed document for testing. Unfortunately, the ET/EST instruments did not pass all tests, although they did demonstrate system stability for field use. It was decided at a meeting at GIMRADA in August 1965 that all three test instruments should be modified to correct deficiencies and that further testing should be suspended until this was completed. It was also decided at this meeting to drop further consideration of the Astro Space instrument. A contract was awarded to Lear Siegler to correct the deficiencies found in testing to date and, in March 1966, one additional instrument was procured at the request of Army Materiel Command to provide maximum support for ET/EST and production engineering (Fig. 160).

Fig. 160. Lightweight Gyro Azimuth Surveying Instrument--ET/EST model.

This modification proved to be unsuccessful. It was found during acceptance testing in late 1966 that in modifying the units earlier design provisions had been disturbed creating additional technical problems. Lear Siegler made numerous changes to overcome the major problems; however, in testing at ETL from June through November 1967, the modified instruments failed to meet the QMR requirements throughout the -65°F to +125°F temperature range. Also, the weight and power requirements were exceeded, and the instrument required heating above 0°F. By this time, the instruments had been through so many hours of environmental testing that the

performance reliability of the instruments was questionable due to the deleterious effects of these tests. It was determined that a complete overhaul of the test instruments would be necessary prior to further testing, and such a recommendation was made to Office, Chief of Engineers, in November 1967.

After a delay of more than a year, ETL was directed by the Army Materiel Command in February 1969 to continue development of new ET/EST models that would meet the QMR. A contract was awarded to Lear Siegler, Inc., on 30 June 1969 for the fabrication of four models and for complete research and analysis of past problem areas.

In September 1970, the fabrication phase of the development was completed and acceptance testing started. After a successful high-latitude test at Fort Greeley, Alaska, however, testing was suspended due to excessive equipment failures primarily in temperature, shock, and vibration with the theodolite and isolator system. While the contractor was working on these problems, ETL recommended that a critical review and update of the QMR be made considering real user requirements versus state-of-the-art gyro equipment to preclude unnecessary damage to the equipment during test and thus further delay in development.

Acceptance testing resumed in January 1971. Four instruments were delivered in March 1971;[343] three of these went to USATECOM for ET/EST and one to Germany for test and evaluation by U. S. Army topographic personnel and the Pershing Missile Command, U. S. Army Europe. After temporary suspension of engineer testing at APG in August 1971 pending Department of the Army approval of the QMR revisions and change to the engineer test plan, service test was satisfactorily completed at Fort Sill in October, changes to the engineer test plan were approved in November, and the revised QMR was approved in December 1971. Expedited completion of all tests and type classification was scheduled for some time in 1972 after almost 12 years of development effort started with the first Lear Siegler contract in 1960.

This development is considered to be one of the major achievements in the surveying instrument development field. It provides instrumentation weighing approximately 40 pounds (excluding batteries) which can be carried by one man, is operable under all-weather, day-night conditions, and provides azimuth accuracy of 1 minute of arc (1 sigma) at mid latitudes.

(10) **Small North Orienting Device (Miniaturized Gyrocompass).** A Qualitative Materiel Development Objective (QMDO) for Small North Orienting Device

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343 "Design and Development of Surveying Instrument: Azimuth, Gyro, Lightweight (SIAGL)," Final Report, Lear Siegler, Inc., March 1971.

(Miniaturized Gyrocompass) was approved on 31 March 1965. (The QMDO was subsequently revised on 17 January 1968.) The objective was to provide a small device weighing not more than 3 pounds which could be carried on a web belt and would determine azimuth to an accuracy of about 2 mils in an operation time of 3 minutes. It would be used by field artillery forward observer and ground surveillance and target acquisition operations to determine accurate orientation

Preliminary studies had been implemented prior to the QMDO approval under a contract with the Astro Space Laboratories, Inc., Huntsville, Alabama, to examine the feasibility of a spinning gyro for this type of application. In these studies from June 1964 to May 1965, two methods of mechanization of the sphere gyro were examined (Figs. 161 and 162)—one with fluid suspension, and the other with air suspension. The air bearing approach was selected.[344]

These preliminary studies were followed by an investigation under contract by Lear Siegler, Inc., Santa Monica, California, from September 1965 to April 1966, to investigate the feasibility of employing a piezoelectrically driven, oscillating glass squeeze bearing. Several designs using first a piezoelectric squeeze bearing in a pendulous gyro configuration and secondly a viscous friction gyro were examined[345] but all were rejected because of complexity and cost.

A development contract for the Small North Orienting Device was awarded to Astro Space Laboratories in May 1967 to produce an experimental model. In December 1967, another development contract was awarded to the Arma Division, AMBAC Industries, Inc., Garden City, New York, to develop a feasibility model using the Arma G-16 Dynature gyro.

After considerable difficulty was encountered in the development of a suitable air pump and also in the development of an appropriate azimuth transfer device, the Astro Space Laboratories instrument was delivered to ETL for test on 20 May 1969. After preliminary tests in which it was found that the device did not meet the accuracy requirements and that the azimuth transfer device was not satisfactory, it was returned to Astro Space Laboratories for redesign of the azimuth transfer device, air supply system, and gyro drive meter with invertor. The redesign was completed by August 1970.[346] After some testing in which it was found that the instrument still did not meet the accuracy requirements (2.38 mils versus the 2-mil requirement) the instrument started to

344"Study and Prototype Model Design of a Miniaturized Gyro Compass," Final Report, Astro Space Laboratories, Huntsville, Alabama, May 1965.

345"Study of the Application of Piezo-Electric Techniques to a Small North Orienting Device," Final Report, Lear Siegler, Inc., Santa Monica, California.

346"Design Studies and Prototype Model Development of a Small North Orienting Device (Miniaturized Gyrocompass)," Final Report, Astro-Space Laboratories, Huntsville, Alabama, August 1970.

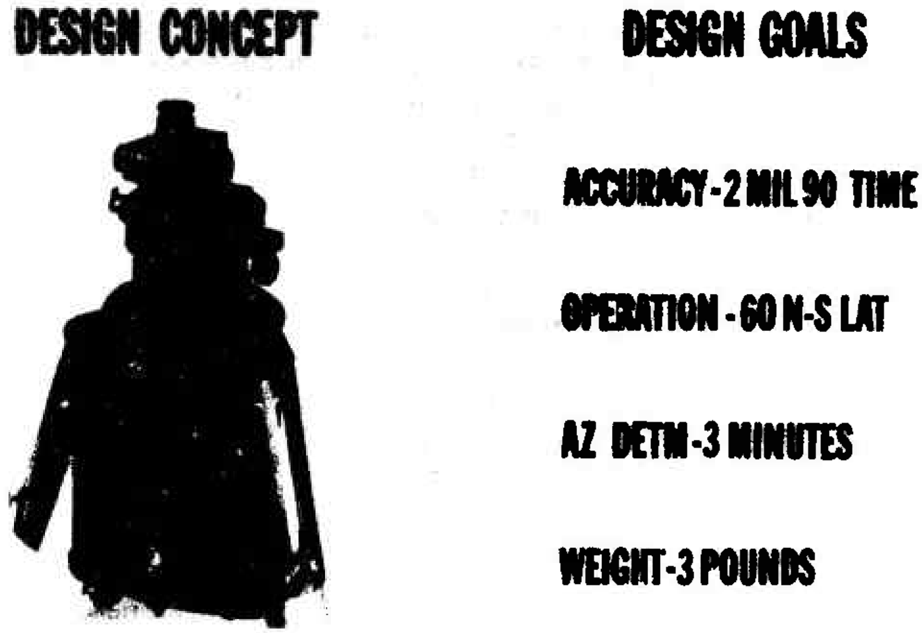

Fig. 161. Miniaturized Gyrocompass—design concept and goals.

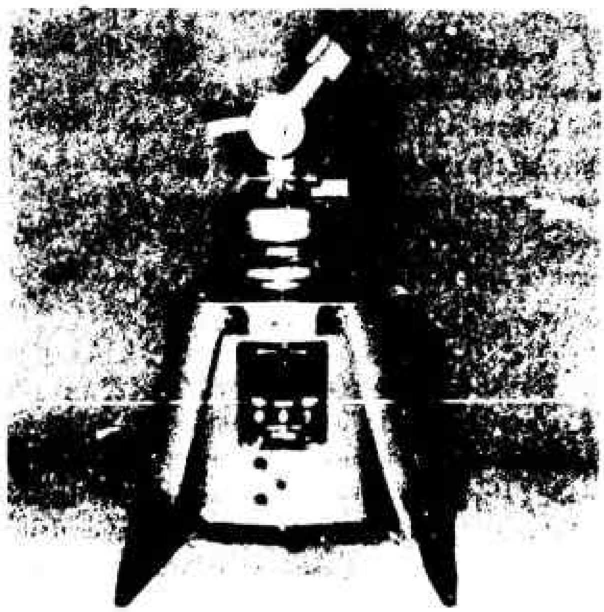

Fig. 162. Miniaturized Gyrocompass—experimental model.

malfunction and the tests were suspended. This instrument far exceeded the weight limitation goal; it weighed 20 pounds without case and 34 pounds with case, but it did meet the goal of a 3-minute read time. However, during the development, it became apparent that weight savings could be realized in several areas, including the azimuth transfer device, the air pump and motor, the gyro drive motor, the gyro sphere, and the instrument housing. The next step in this development was a redesign to accomplish the desired weight reduction.

The American Borch Arma Corporation model was delivered to ETL on 3 February 1969. It too, was returned to the contractor after preliminary testing for improvement of performance, although the accuracy of the device was well within requirements on most tests.[347] The principal problem was that the instrument performed erratically when subjected to high winds, and the nulling mechanism operated roughly during the latter stages of testing.

Based on engineering design tests[348] completed after the return of the device to ETL in August 1969, it was concluded that considerable additional research and development were required to minimize the effects of wind, shield the instrument from magnetic forces, reduce the observation time from the 9 minutes required in tests, correct several mechanical deficiencies, and reduce the size and weight. The total package weight of this instrument was 51 pounds.

(11) **Sequential Collation of Range (SECOR) System.** In April 1960, the Army Map Service contracted with the Cubic Corporation, San Diego, California, for a Geodetic Sequential Collation of Range (SECOR) System. The objective was to provide a system, which through techniques of electronic ranging to an orbiting earth satellite, would provide means for establishing geodetic positions of points of distances of 100 to 1500 miles from known geodetic positions. Thus, the system would provide means for making intercontinental and inter-island datum ties – a fundamental geodetic problem at that time.

The 1960 Army Map Service procurement was for four prototype ground stations and a prototype satellite transponder unit to be orbited in a U.S. Navy transit system satellite to test and demonstrate the system. In operation, three of the ground stations would be positioned on known geodetic positions and the fourth on an unknown point. The system would provide recorded ranging data from each of the ground stations to the satellite during each orbital pass at the rate of 20 ranges per second. With this configuration, two modes of operation were possible; a simultaneous

[347] "Development of a Small North Orienting Device," Final Report, AMBAC Industries, Inc., Garden City, New York, February 1970.

[348] Allan R. Holland, Sr., ETL-ETR-70-11, "Miniaturized Gyrocompass (Small North Orienting Device)," November 1970.

mode wherein all ground stations ranged on the satellite simultaneously; and an orbital mode wherein an updated satellite orbit established by the ranging data from the known positions was used to compute the unknown positions through its nonsimultaneous ranging data. Accuracy could be improved by using several orbital passes. The system could also be used in a line crossing mode wherein simultaneous ranging data to the satellite could be used to compute the geodetic distance between stations as it crossed the line between two stations.

Preliminary system tests were conducted in the spring of 1961, and the Army Map Service contracted for two additional ground stations which were designed "ruggedized" stations since special consideration was given to transportability in their design and construction. However, system tests conducted in the fall of 1961 raised questions as to the validity of the basic system concept, and the entire program was halted by the Office, Chief of Engineers, for re-evaluation.

On 15 January 1962, GIMRADA was directed to form an evaluation team to investigate the SECOR program. The team, composed of scientists and experts from GIMRADA, Ballistics Research Laboratories, and the National Bureau of Standards, made an expedited but complete analysis of the system, determined that the basic concepts were valid, and recommended a program of development to ensure reliable operation meeting the desired system accuracy.[349]

In February 1962, the research and development phase of the SECOR program was assigned to GIMRADA, and on 19 February 1962, GIMRADA was directed to contract for equipment modification in accordance with the evaluation team recommendations. An expedited development program was requested, and contracts were awarded soon thereafter for incorporation of these modifications in two of the prototype ground stations and the two ruggedized stations. The evaluation team remained active in the program in a consulting basis, and assisted in the development of the system by frequent inspections and in-process reviews. In addition, a resident engineer office was established in the Cubic Corporation Plant to monitor all SECOR contracts. In June 1962, GIMRADA contracted with the Cubic Corporation for four additional ruggedized ground stations (Fig. 163). All ground stations were delivered by November 1963.[350]

In the meantime, development of satellites and transponders was also in progress. GIMRADA procured four Type I satellites (Fig. 164) from Cubic Corporation in February 1961[351] and an additional satellite from International Telephone

[349] J. T. Pennington and Others, "Review and Analysis of U. S. Army Geodetic SECOR System and Development," Special Report, February 1962.

[350] "Geodetic SECOR Ground Equipment," Final Report, Cubic Corporation, March 1964.
"Ruggedized Geodetic SECOR," Final Report, Cubic Corporation, May 1964.

[351] "Geodetic Spacecraft," Final Report, Cubic Corporation, October 1961.

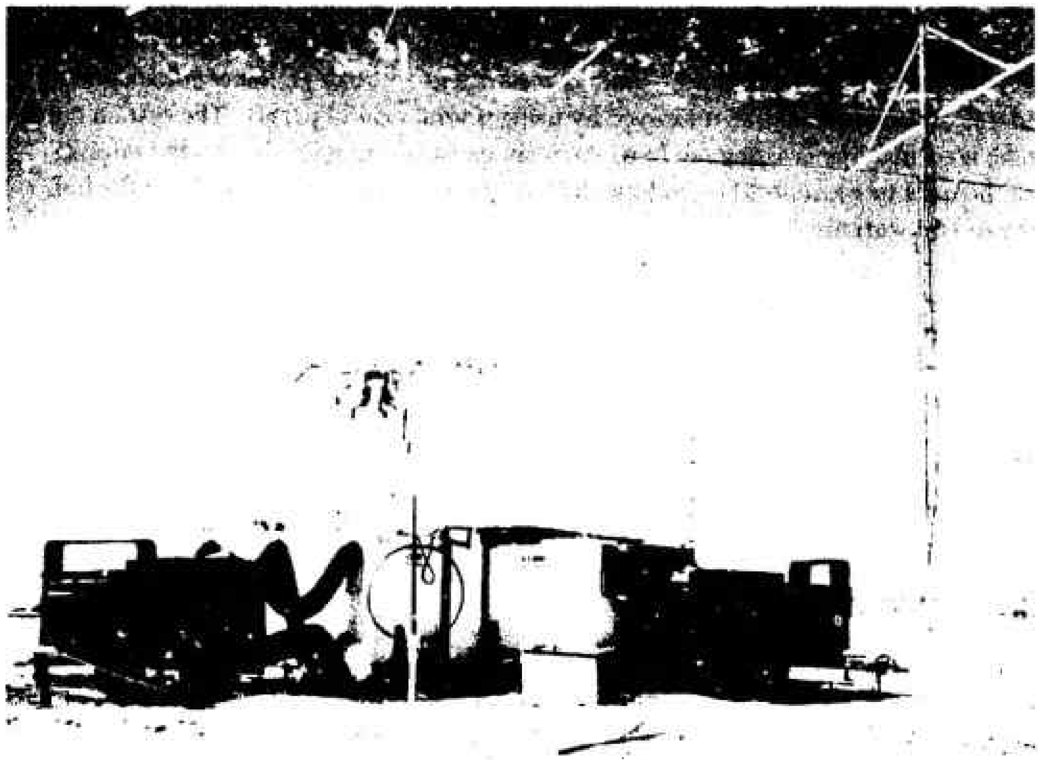

Fig. 163. SECOR Ground Station—1965.

and Telegraph Federal Laboratories (ITTFL) in October 1962.[352] This later satellite was, unfortunately, destroyed during predelivery vibration tests. Following this experience, a contract was awarded to ITTFL in March 1963 for three Type II satellites,[353] a box-type configuration (Fig. 165). One of these was successfully launched on 11 January 1964 for combined engineer/service test for which tracking operations began on 12 January 1964.

The combined engineer and service tests of the system, with Army Map Service participation, were completed in May 1964,[354] just a little over 2 years after the assignment of development responsibility to GIMRADA. In these tests, the system was found to be capable of measuring ranges exceeding 3000 kilometers to the satellite. The coordinates of positions were determined with an average error vector magnitude of 16.6 meters on a 500-mile quad and of 33.6 meters on a 1000-mile quad.

352"Type I Geodetic Satellite," Final Report, ITT Federal Laboratories, June 1964.

353"U. S. Army Type II Geodetic Satellites," Final Report, ITT Federal Laboratories, November 1965.

354"Combined Engineer and Service Test, Geodetic SECOR System," Draft Technical Report, Prepared by Advanced Geodetic Developments Branch, Surveying and Geodesy Division, GIMRADA, 1 July 1964.

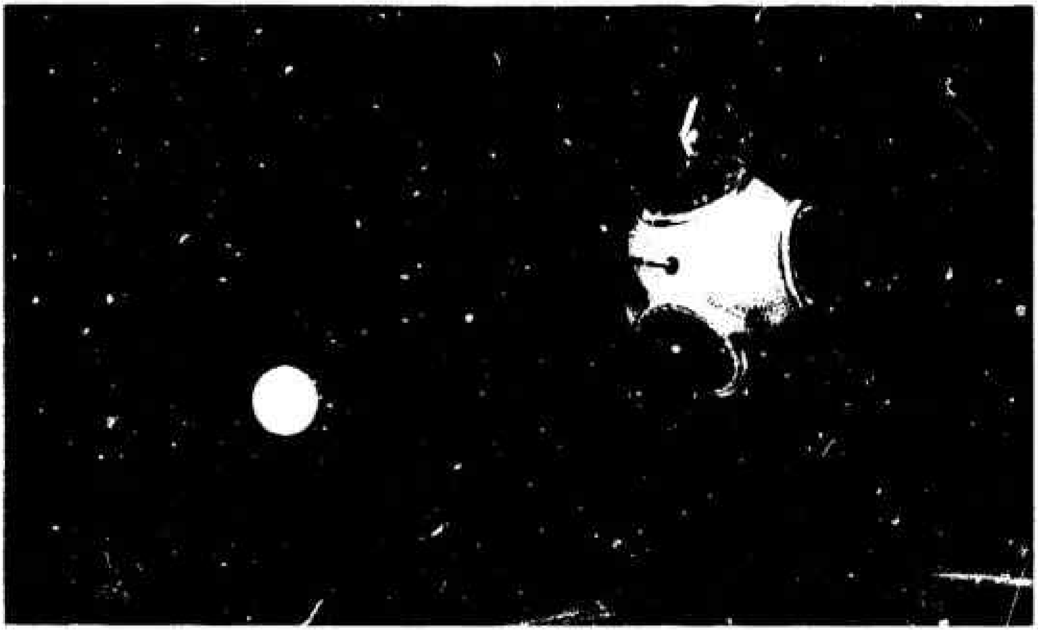

Fig. 164. SECOR Type I Satellite.

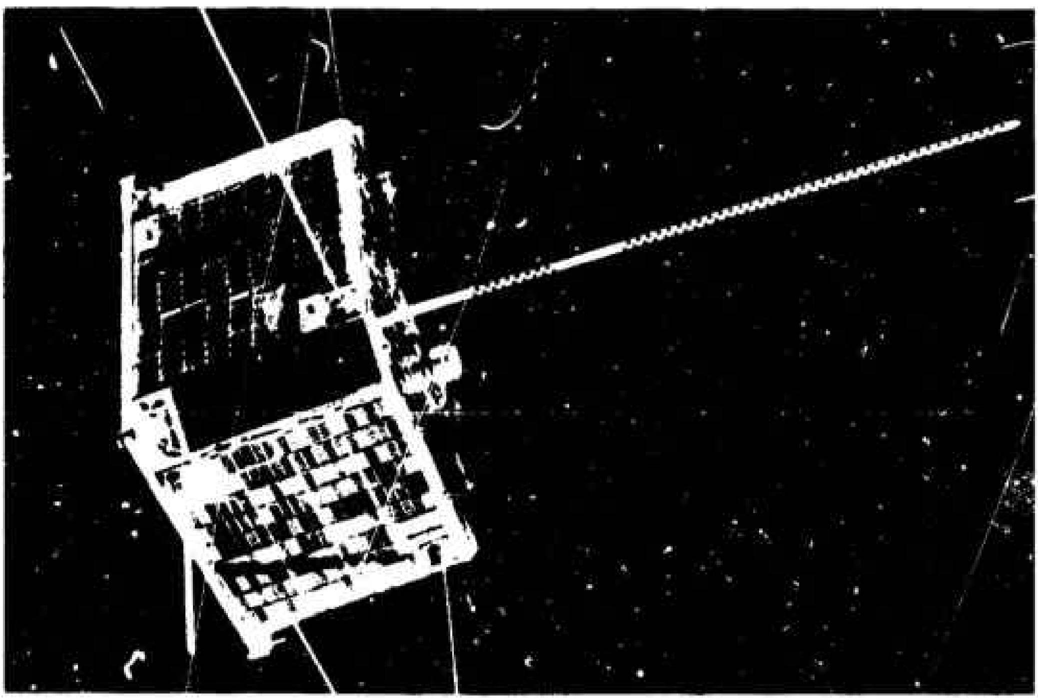

Fig. 165. SECOR Type II Satellite.

As a part of these tests, a geodetic distance exceeding 3500 kilometers was measured—San Diego, California, to Herndon, Virginia. It was concluded from these tests that the equipment showed great potential as a first-order survey tool, and the equipment was turned over to the Army Map Service for implementation of an operational program of long-range geodetic measurement.

GIMRADA continued work on the SECOR System in support of the ground operations and in an active program of satellite and transponder development. Also, GIMRADA was charged with the responsibility for satellite launches throughout the life of the program, with the exception of a few launches in the late 1960's which were considered strictly operational and not involving new equipment. Most of the satellite launches were "piggy-back"; that is, they were the secondary pay load on boosters launching satellites primarily for some other purpose. In November 1965 and again in January 1968, SECOR transponders were launched as an integral part of combined Department of Defense and National Aeronautics and Space Administration geodetic satellites designated GEOS A and GEOS B respectively. A complete satellite launch history starting with the 11 January 1964 launch for combined engineer and service tests is shown in Table 3.

The development program, which paralleled the operational program in the mid to late 1960's, included contracts with the Cubic Corporation for Type II satellite and High Altitude Transponders (HAT) and with the ITT Federal Laboratories for Multi-Altitude Transponders (MAT) in mid-1965. In late 1966, the Defense Intelligence Agency authorized the development of miniaturized ground stations. These reduced the number of shelters for each ground station from three to one and effected an 8:1 reduction in ground-station weight. A total of eight of these stations was procured from the Cubic Corporation, and four were placed in operation in the field before the program was terminated. Late in 1967, Cubic Corporation produced an improved HAT, and the first MAT production models were produced by ITT.

The entire SECOR program was terminated in April 1970 on completion of an equatorial belt of geodetic control stations.

(12) Translocation Field Equipment. Interest in the Doppler Translocation Field Equipment as a possible solution to Army artillery and mapping survey problems started in the early 1960's. In 1964, a contract was awarded to the Westinghouse Electric Corporation, Baltimore, Maryland, to conduct experiments with Doppler satellite tracking instrumentations to demonstrate the potential of the systems for Army applications. These experiments, using Doppler satellite tracking instrumentation developed for the U.S. Navy, were completed in May 1965 (Fig. 166).[355] In the meantime, in

[355] "Doppler Satellite for Army Field Operation," Final Report, Westinghouse Electric Corporation, Baltimore, Maryland, May 1965.

Table 3. SECOR Satellite Launch History

15 January 1971

Name	Launch Date	Satellite	Transponder	Incl	Period (min)	Apogee	Perigee	Remarks
EGRS I	11 Jan 64	Type II (S/N-2) ITT	TR-27 Cubic	69.91°	103.4	928 km	916 km	Success. Ceased operation Sep 65 after approximately 1100 interrogations.
EGRS III	9 Mar 65	Type II (S/N-1) ITT	TR-27 Cubic	70.09°	103.5	942 km	906 km	Success. Not used operationally after Jul 67. Completed 1200 interrogations.
EGRS II	11 Mar 65	Type II (S/N-3) ITT	TR-27 Cubic	89.98°	97.5	992 km	982 km	Launcher failed to separate satellites. Re-entered 26 Feb 68.
EGRS IV	3 Apr 65	Type II (S/N-5) ITT	C-101 ITT	90.20°	111.4	1324 km	1266 km	Experimental transponder failed during launch.
EGRS V	10 Aug 65	Type I (S/N-2) Cubic	TR-27 Cubic	69.24°	122.2	2427 km	1135 km	Excessive spin rate. Ceased operation Mar 66, after approximately 50 interrogations.
GEOS A	6 Nov 65	GEOS APL	TR-27 Cubic	59.38°	120.3	2273 km	1119 km	Success. Ceased operation Jan 67, after approximately 500 interrogations.
EGRS VI	9 Jun 66	Type II (S/N-7) Cubic	TR-30A Cubic	90.04°	125.2	3655 km	171 km	Highly elliptical orbit due to launcher failure. Not useful. Re-entered 6 Jul 67.
EGRS VII	19 Aug 66	Type II (S/N-8) Cubic	TR-30A Cubic	90.01	167.9	3743 km	3686 km	Experimental transponder 75% useful. Battery failure in Jan 67 after approximately 200 interrogations.
EGRS VIII	5 Oct 66	Type II (S/N-9) Cubic	TR-30A Cubic	90.19°	167.6	3704 km	3677 km	Transponder apparently failed during launch.

Table 3 (cont'd)

Name	Launch Date	Satellite	Transponder	Incl	Period (min)	Apogee	Perigee	Remarks
EGRS IX	29 Jun 67	Type II (S/N-10) Cubic	TR-30A Cubic	89.8°	172.1	3945 km	3794 km	Success. Still usable after approximately 1800 interrogations.
GEOS-B	11 Jan 68	GEOS APL	TR-30A Cubic	105.8°	112.2	1573 km	1080 km	Success. Not used operationally after Jan 70. Completed 600 interrogations.
EGRS X	18 May 68	Type II (S/N-4) ITT	Proto MAT ITT	99°	106	1100 km	1100 km	Launcher failed to achieve orbit.
EGRS XI		Type II (S/N-13) Cubic	TR-30B Cubic					
EGRS XII	16	Type II (S/N-[illegible]6)	MAT ITT	91.3°	172	3900 km	3900 km	Dual payload. Launcher failed to achieve orbit.
EGRS XIII	1[illegible] Apr 69	Type I (S/N-14) Cubic	TR-30B	99.9°	107.3	1141 km	1085 km	Success. Still operational after approximately 50 interrogations.
TOPO I	8 Apr 70	Type II (S/N 18) ITT	MAT ITT	99.86°	107.0	1096 km	1081 km	Success. Still operational after approximately 50 interrogations.

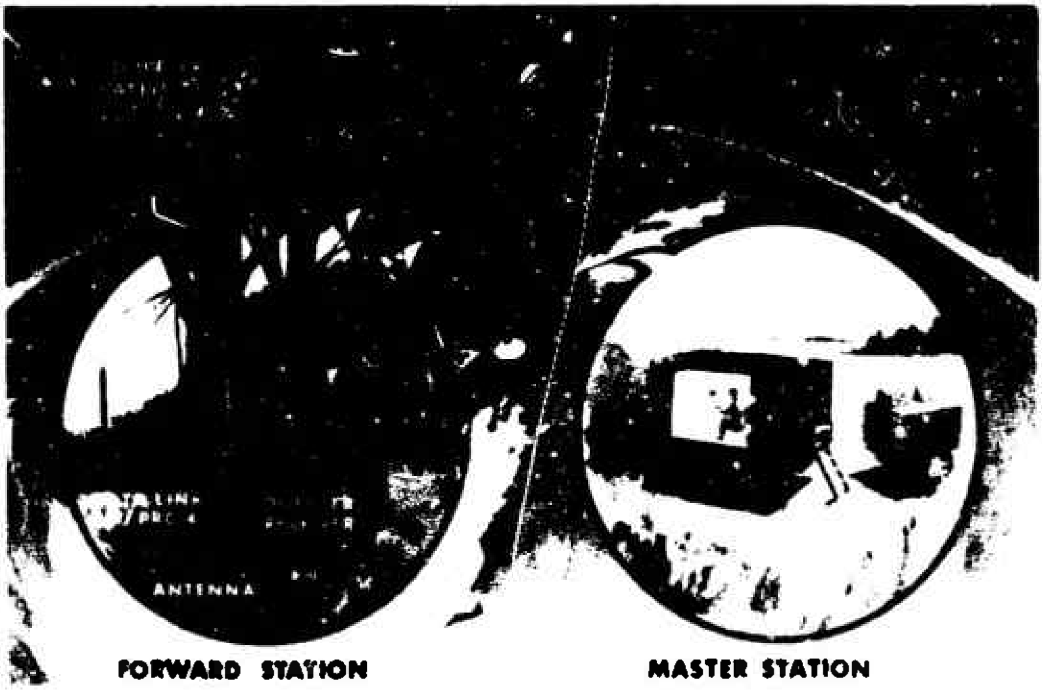

Fig. 166. Doppler translocation concept.

December 1964, the U. S. Navy conducted tests demonstrating the principle at the Quantico Marine Base. These tests were witnessed by GIMRADA personnel. In April 1965, it was learned that the U. S. Navy planned to develop a set of translocation field equipment, consisting of two identical 40-pound backpacks, which would determine relative positions between two points at short as well as long range by tracking U. S. Navy Doppler Navigation Satellites.

This development was an outgrowth of the U. S. Navy Navigation Satellite Systems development—a system in which the orbiting satellite uses a very stable oscillator to transmit a continuous RF signal with orbit ephemeral data and timing signals transmitted at 2-minute intervals. These RF signals were received on the ground or aboard ship and compared with a stable oscillator to measure the Doppler shift, which, together with the orbital information, provided the basic data to compute the position of the ground or shipborne station. From the Doppler data from two or more of these ground stations, one of which was designated a master station and located on a known position, the relative positions of the various stations could be computed.

In May 1965, funds were transferred to the U.S. Navy for two single-frequency Doppler translocation receivers (backpacks) (Fig. 167). These were received

Fig. 167. Doppler Translocation Receiver—experimental model.

Fig. 168. Doppler Translocation Master Station—experimental model with FADAC computer.

in March 1967 and a test program with the U. S. Navy was conducted in the summer of 1967. A FADAC computer was used with this equipment for data reductions (Fig. 168).

The results of these tests indicated a potential application of this type of equipment for tactical positioning purposes providing certain modifications in the equipment and computer programs were accomplished. Following these tests, the Navy continued the development of advanced receivers under contract with Honeywell, Inc. (Fig. 169), and plans were being made in 1970 for further field tests by the Army and the U. S. Marines to determine the full potential application for tactical positioning.

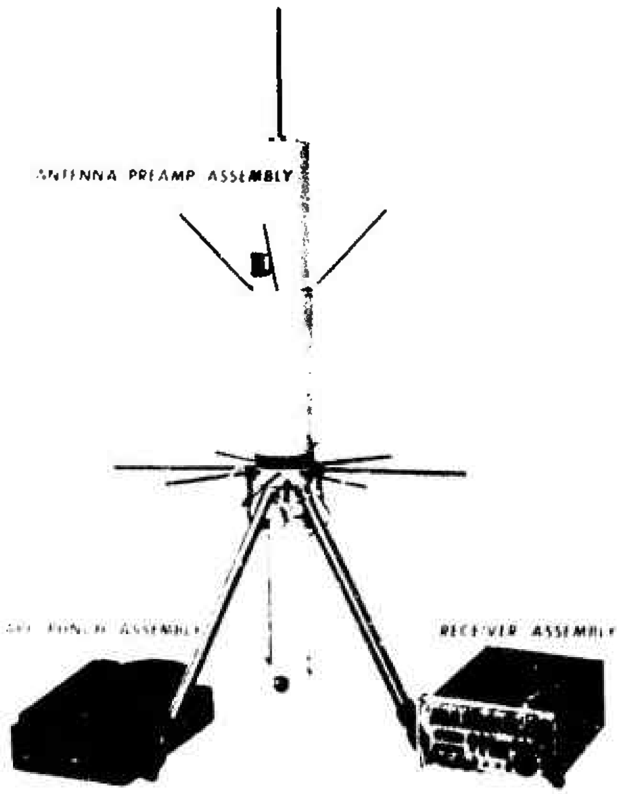

Fig. 169. Geoceiver System for Doppler Translocation.

(13) All-Weather Angle Measuring. In June 1964, GIMRADA awarded a contract to the Cubic Corporation, San Diego, California, for the design, fabrication, and test of a microwave pointing system to verify the feasibility of using a transmitted microwave signal to achieve collimation between the transmitter and the receiver, thereby extending the useful operational time of angle determination to all-weather conditions. Prior to this time, GIMRADA had funded experiments in microwave pointing by the National Bureau of Standards, Boulder, Colorado, and in Hawaii at frequencies of

Fig. 170. Electronic Angle Measuring Equipment: 35 GHz.

9.4 and 18.8 GHz. The equipment produced by the Cubic Corporation operated at 35 GHz (Fig. 170).[356]

Following experiments with this equipment in 1965, which included tests at Boulder, Colorado, in July 1965 to obtain simultaneous data pertaining to long-term and short-term signal angle-of-arrival variations at 9.4-, 18.8- and 35-GHz frequencies over the same path[357] and tests conducted at Fort Belvoir, Virginia, in the period 14 September through 28 October 1965 to determine the feasibility of angle measurement at a fixed frequency instead of multiple frequencies,[358] another experimental equipment operating at 90-GHz frequency was procured under contract (Fig. 171). This equipment demonstrated the reduction in size and weight which could be realized using the higher frequency. By 1970, these experimental devices had demonstrated absolute angle measurement accuracies better than five records of arc although

[356] "Electronic Pointing Device (Microwave) System (Electrotransit)," Final Report, Cubic Corporation, San Diego, California, February 1964.

[357] Peter J. Cervarich, GIMRADA Report 26-TR, "Microwave Pointing Variations and Angle Measurements," January 1966.

[358] Mahlon C. Hawker, GIMRADA Report 33-TR, "Fixed and Multiple Frequency Angle Measurements with 35GHz Microwaves," October 1966.

the equipment was rather bulky for man-portable applications. The next step in the logical course of development of this class of equipment involved a combined distance and angle measuring system with emphasis on short ranges and a more compact configuration of equipment. In 1970, this further development was projected to provide a system which, when completed, will permit field survey units to extend control by triangulation, trilateration, and traverse techniques during adverse climate conditions.

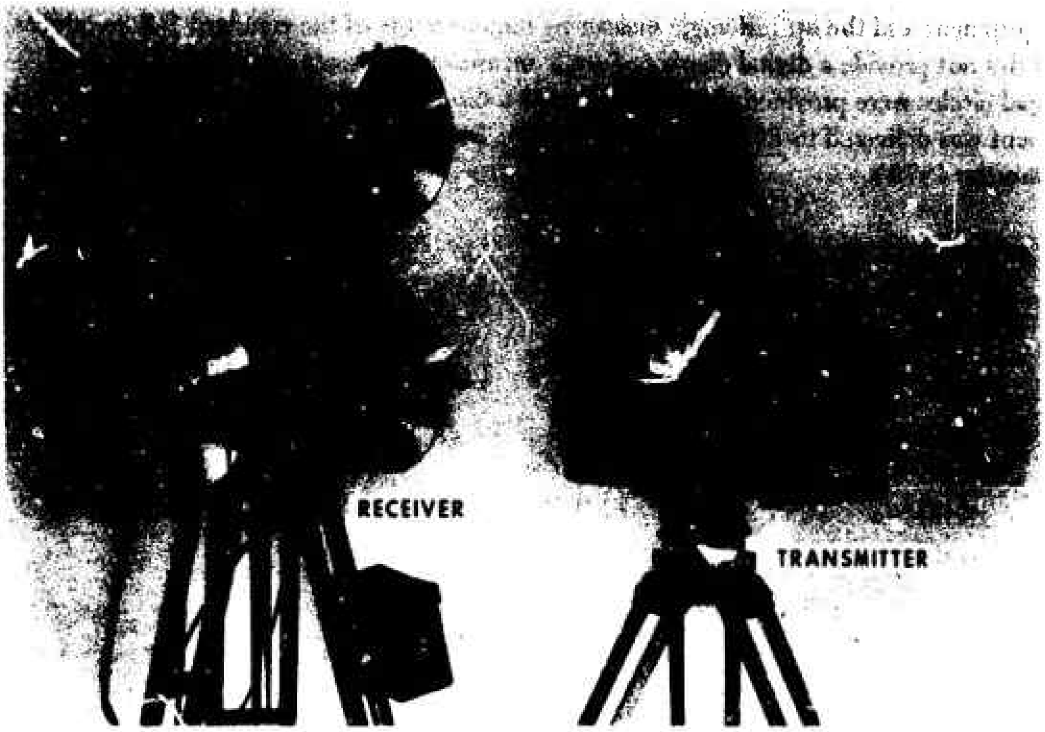

Fig. 171. Electronic Angle Measuring Equipment: 90 GHz.

(14) Distance and Angle Measuing System. As early as 1964, the U.S. Army Combat Developments Command Artillery Agency proposed a Small Development Requirement (SDR) for a small, lightweight equipment to measure azimuth and distances over limited range and to provide low-order accuracy to be used for fourth order survey in field artillery surveying operations. The work on all-weather angle measuring previously discussed was directed toward an eventual application in such an instrument. Another exploratory development of the mid-1960's with possible application in such equipment in the future was a Theodolite with Shaft Angle Coder and Digital Display produced by the Perkin-Elmer Company under a GIMRADA contract in 1967.[359] [360] This item proved

[359] "Theodolite with Shaft Angle Encoder and Display," Final Report, Perkin-Elmer Company, June 1967.

[360] "Optical Theodolite Readout," Final Report, Perkin-Elmer Company, Norwalk, Connecticut, June 1967.

the feasibility of using a state-of-the-art angle encoder for military surveying although the equipment produced was heavier than desired.

In 1968, ETL contracted with the Elgeo Corporation of America for two prototype instruments called the ELGEO which combined the function of angle and distance measurement in a single instrument. This instrument was aimed at meeting the microwave ranging requirements of the then standard microwave distance-measuring equipment and the optical angle measuring requirements of the standard T-2 theodolite. It did not provide a digital display of angle measurements since conventional visually read circles were provided, but it did provide a direct digital display of range. This equipment was delivered to ETL in 1969 (Fig. 172). Engineer test of this equipment continued into the 1970's.

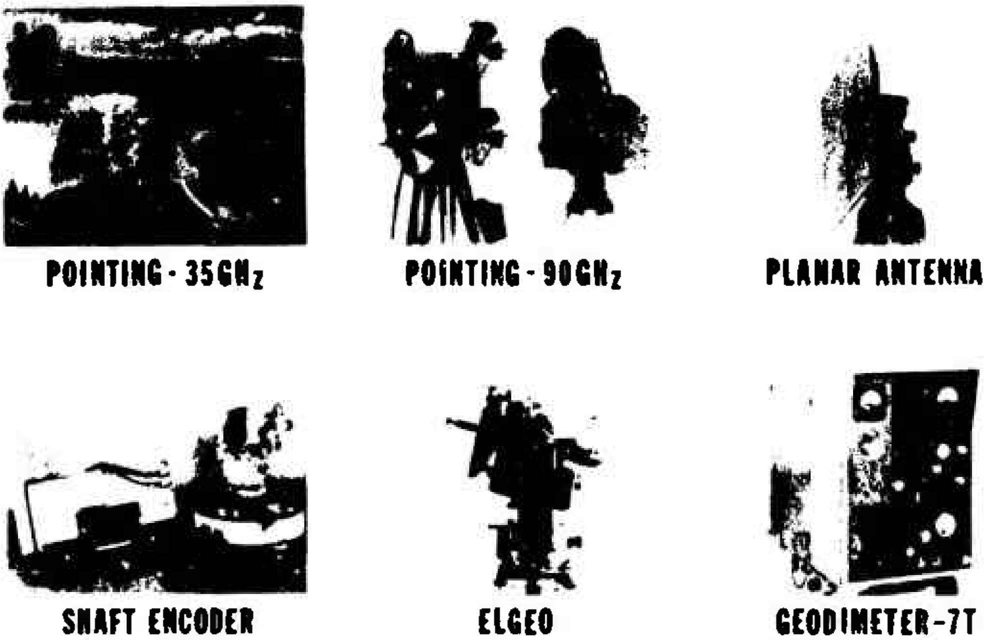

Fig. 172. Distance and Angle Measuring Equipment (DAME) investigations.

Paralleling this development, a number of similar developments for the commercial market were being investigated by ETL. These included the Geodimeter T-7 which provided optical angle measurement with conventional visually read circles and direct digital display of range and the REG ELTA-14 produced by Zeiss which provided direct digital readout of both range and angle. Also under consideration was the possibility of retrofitting encoders on standard theodolites.

These investigations demonstrated the feasibility of development in the 1970's of all-weather, day-night, combination distance-measuring and angle-measuring instruments with automatic reading and processing capability in a format ready for interface with modern command and fire control systems.

g. Geographic Sciences.

(1) **Development of Research and Development Program.** In contrast to surveying, geodesy and mapping, there had been virtually no research and development devoted to the improvement of the collection, processing, and dissemination of terrain information (usually referred to as military geographic information (MGI)) since World War II. With the activation and organization of GIMRADA in 1960, an operating element called the Intelligence Division was established. This element was responsible for research and development in this area.

During the next several years, with a small staff of only a few individuals acquired by transfer from other elements of GIMRADA, efforts were concentrated on investigation of MGI operations in the Army to gain a familiarity with terrain intelligence production source materials, methods, and products and an understanding of those problem areas which reflected a requirement for research and development support. Also during these early years, through contacts with industry, some feasibility type determinations were made at no cost to the government through research and development loan agreements. Significant studies of this type were made in the areas of radar calibration, pattern recognition, and the determination of photo interpretation problems. In addition, work started on the development of a program to modernize the engineer detachments (terrain) so that they might perform their function better in support of the field army. A program was also initiated in support of the space application element of the National Aeronautics and Space Administration.

These early activities and investigations finally led to the authorization of an exploratory development project titled Military Geographic Intelligence (MGI) in October 1964. The project approval actually came before the QMDO was approved in early 1966 based on the fact that a suitable QMDO was well along in the staffing process. The objective of the MGI project was to conduct applied research, exploratory development, feasibility studies, and evaluation of new techniques to improve systems, including equipment for collecting, processing, analyzing, storing, and disseminating military geographic data for field army and strategic uses to meet MGI requirements. Initially, the project was set up with two tasks:

Task 1: Exploratory Development in Support of Collection, Processing, and Presentation of MGI.

Task 2: Exploratory Development in Support of Automatic Data Processing of MGI Data.

This project structure was later changed to provide more effective management in FY 71 and beyond, providing five task areas as follows:

(a) 01–Analysis of MGI Requirements and Definition of Systems Concept
(b) 02–MGI Data Collection
(c) 03–MGI Data Reduction
(d) 04–MGI Product and Analysis Definition
(e) 05–MGI Data Handling

In FY 69, an advanced development project–Military Geographic Intelligence System (MGIS)–was approved. Its objective was to improve the capability of the Army to interpret the output of imaging and nonimaging remote sensors to obtain military geographic information; to design new MGI products, displays, and readouts to support specific types of military activities; and to design and operate an experimental automated system for the storage, retrieval, manipulation, and analysis of military topographic information.

This project included four tasks:

(a) 01–Radar Ground Data Reduction for MGI
(b) 02–Ground Data Reduction of Photography for MGI
(c) 03–MGI Products, Displays, and Readouts
(d) 04–MGI Data Base

While these approved, numbered research and development programs in the MGI areas were being developed and processed in the 1960's, the staff of the Intelligence Division (later renamed successively Geographic Intelligence, Geographic Sciences, Geographic Systems, and Geographic Sciences) was involved in a number of other programs, both within and outside the Department of Defense, all of which were related to and supported the overall MGI effort. The more significant of these programs as well as specific efforts under the numbered development project effort will be described in subsequent sections of this history.

(2) **Modernization of Terrain Detachments.** One of the earliest efforts in the Geographic Sciences area was an analysis of the capabilities of engineer detachment (terrain) to perform its mission in support of the modern field army. This analysis was made in 1963 and indicated that the detachments were operating with obsolete equipment and procedures which seriously hampered their ability to produce terrain

data of the quality, quantity, and timeliness required. As a result, the preparation of a QMR to authorize research and development of state-of-the-art equipment methods and techniques was started.

A draft QMR was prepared in 1964 through 1965; but, on review by the Combat Development Command Engineer Agency, it was suggested that an SDR would be more suitable. Higher priority work prevented further effort on this item until 1968. In that year, it was recommended that a project be initiated under the Expedited Nonstandard Urgent Requirements for Equipment (ENSURE) program as an expedited method to get equipment to the troops in Vietnam.

Although the ENSURE program approach was not approved by higher authority, a state-of-the-art equipment brochure was prepared in 1968 and 1969 and was provided to units in Vietnam for their use in requesting items by the ENSURE route. Late in 1969, a review of the original QMR was initiated, and in early 1970 a draft SDR including all changes in the state-of-the-art that had occurred was finally completed for review by the Combat Developments Command Engineer Agency and the U.S. Army Topographic Command.

(3) **NASA Support Program.** After extensive conferences and discussions in 1963 with personnel of the space applications element of the National Aeronautics and Space Administration, a program was developed to support them in the general area of research and development concerning earth resources. Eventually, 10 additional personnel spaces were allocated to ETL for this program.

This program continued for about 4 years. In addition to the actual work performed under NASA purchase request, there was considerable exchange of information, which included remote sensing and geography through participation in conferences, seminars, and committees. The program included primarily studies in color and multispectral photography,[361] [362] the preparation of an earth atlas[363] to show the potential of studying the earth from orbiting spacecraft, and the preparation of a bibliography of remote scanning resources.[364] Mr. D. C. Orr of the Geographic Sciences staff was loaned on a 6-month TDY in 1967 to develop specifications for a multiband camera.

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[361] A. Anson, "Feasibility of Objective Color Systems," September 1964.
"Preliminary Report on Multispectral Experiment," February 1965.
"Supplement to Preliminary Report on Multispectral Experiment," June 1965.
"Multispectral Experiment No. 2."

[362] D. L. Orr, "Multiband Color Photography for Space Application," ASP Semi-Annual Meeting, October 1967.

[363] R. A. Leestma, "The Use of Multisenser Imagery From Space in Portraying the Earth and the Multisensor Imagery Collection," 1966.

[364] N. E. Jones (Kothe), "Bibliography of Remote Survey Resources," September 1966.

He was named the coordinating investigator for a multiband photographic spacecraft experiment to survey earth resources. A multiband camera experiment of six mapping cameras with spectral filters and selected films was defined and approved by NASA for a future space flight. The definition of this experiment involved consolidating the requirements of a large number of user scientists in national organizations concerned with earth sciences application. A preliminary multiband experiment consisting of four Hasselblad cameras was flown on the Apollo IX spaceflight.

The earth atlas program, started in July 1964, proved to be a highly successful project providing the best and most comprehensive publication prepared from NASA-generated imagery up to 1970. On initiation of this project, a draft sample was produced and delivered to NASA in August 1965. In November 1965, NASA directed that an improved draft sample be produced in 6 months to include photos taken from Gemini Spacecraft Missions IV and V of June and August 1965 respectively. In May 1966, a dummy copy of the improved draft sample was delivered to NASA. Six days later, NASA requested that the title of the earth atlas be changed to: "Application of Air and Spaceborne Sensor Imagery for the Study of Natural Resources – Sample Analyses and Interpretation Relating to Agriculture, Cartography, Geography, Geology, Hydrology, Meterology, and Oceanography." They were persuaded to shorten the title to "Earth Resources Surveys From Spacecraft." NASA requested 25 copies to be reproduced photographically to ensure the absolute highest quality. Later, in May 1967 and again in May 1968, NASA Manned Spacecraft Center, Houston, Texas, requested 50 additional copies of the publication on each occasion.

In connection with the NASA support activity, it was proposed in 1965 that a Technical Application Center be established at ETL to be operated under the Chief of Engineers as an extension of the NASA staff and with NASA funding to include support by contract activities. This did not materialize however; a Technical Application Center, similar in concept, was set up for NASA by the U.S. Geological Survey.

(4) **Aerial Color Photography**. In addition to and concurrent with the color photography investigation in support of NASA and continuing beyond the NASA program, members of the Geographic Sciences staff maintained a continuing program of investigation of the application of aerial color photography to MGI. In connection with this activity, Mr. Anson of the Geographic Sciences Division staff, became deeply involved with the work of the American Society of Photogrammetry Color Photography Committee and was appointed associate editor of the Manual of Color Aerial Photography which was published by the American Society of Photogrammetry in 1968. During the period 1964 to 1970, Mr. Anson published a number of technical papers dealing with the application of color photography.[365]

[365] See papers listed in ETL-SR-70-1, "Bibliography of In-House and Contract Reports," August 1970, pp 30-31, and ETL-SR-70-3, "Bibliography of In-House and Contract Reports," Supplement 1, October 1971, pp 8.

At the start of these investigations in 1964, and after a series of visits to government agencies and civilian manufacturers, a technology brief was published titled "Status of Aerial Color Photography in Government Agencies" reporting on the state-of-the-art of cameras, films, and projection equipment. Meanwhile, film coverage from several emulsions over the Bennettsville, South Carolina, test area was obtained through the American Society of Photogrammetry Color Photography Committee and was evaluated with the cooperation of several government agencies and private industry.[366]

A direct result of the report on the Bennettsville test was further field tests of the metric aspects of color photography. In September 1967, while on active duty at the Geographic Sciences Division, Col. D. W. Mintzer produced a study report on photography for soils and terrain data.[367]

All this work led to the creation of a task, investigation of aerial color photography for mapping, under the exploratory development for mapping and geodesy project; responsibility was assigned to the Geographic Sciences Division. Under this task in the late 1960's, tests of the GIGAS Zeiss orthoprojector were made to determine feasibility of printing color orthophotographs directly from color negatives onto color sensitized materials; tests were made to determine the feasibility of compiling directly from color photography on the UNAMACE; and in-house studies were made of methods of controlling contact printing and processing of aerial color photography. Special color separation equipment was procured from Technical Operations, Inc., to support these in-house investigations directed toward the production of color topographic products.

Further work in the application of color photography in the MGI area utilized the expertise of Dr. Al Lind and Dr. Jack Rinker of the Cold Regions Research and Engineering Laboratory (CRREL) through transfer of funds. Two ETL technical reports were produced and published in 1970.[368] [369] Also, with the assistance of the field office at Wright Patterson Air Force Base, a contract was let to Fairchild Camera and Instrument Corporation to modify a T-11 camera by the incorporation of a GEOCON I lens to provide a high-resolution, low-distortion, color-corrected cartographic camera. The objective here was an improvement in the state-of-the-art of color photography.

[366] A. Anson, TN-66-3, "Comparative Photointerpretation from Panchromatic, Color, and Ektachrome Photography," February 1966.

[367] O. W. Mintzer, ETL-38-TR, "A Comparative Study of Photography for Soils and Terrain Data," April 1968.

[368] A. O. Lind, ETL-54-TR, "An Evaluation of Multiband and Color Aerial Photography for Selected Military Geographic Intelligence in a Subtropical Desert Environment," January 1970.

[369] R. K. Reed and J. N. Rinker, ETL-TR-70 6, "Evaluation of Color Test Photography for Military Geographic Analysis – A Literature Review," July 1970.

(5) **Multiband Photography**. Concurrent with the multiband photography investigation in support of NASA, ETL pursued a program of investigation of the potentials of multiband photography for application to military geographic analysis. A contract for controlled laboratory and field experiments to determine techniques for extracting military geographic information through the use of multiband photography was awarded to the Aeronutronics Division of Philco Ford Corporation in June 1965. The results of this contract[370] indicated that only four bands of the photographic spectrum were required to extract information on a variety of terrain materials and military targets. Previously, the scientific community had generally considered that nine or more bands were required for terrain analysis.

When the NASA support program was terminated in 1967, efforts were directed toward development of a consolidated, long-range research and development plan for both color and multiband photographic systems to support the Army's MGI requirements.

As a result, several procurements were implemented in the late 1960's. An experimental multiband camera system and an additive color viewer were defined, and contracts for development were awarded in November 1969. A procurement was also initiated for an interference imaging system using defraction gratings for recording color and black and white film.

(6) **Radar Applications for MGI.** The geoscience potential of side-looking radar was a subject for continuing study and investigation, both in-house and under contract, since the implementation of the Geographic Sciences program at ETL. The first contracted studies were made by Autometric Operations of Raytheon Corporation in 1965.[371] This was followed in 1966 by an experimental production of MGI products.[372] In 1969, Purdue University, under contract, investigated the use of side-looking radar imagery for engineering soils studies;[373] and in 1970, Mr. Pearson completed an in-house study related to the use of side-looking radar imagery.[374] As a part of these investigations, Hughes Aircraft Company was funded in 1966 to study the exploitation of the intelligence potentials of coherent radar signals, taking advantage of image signal

370 "Investigation of Multiband Photographic Techniques," Volume I, Final Report, Philco Ford Corporation, Aeronutronics Division, November 1965.

371 "Geoscience Potentials of Side Looking Radar," Final Report, Raytheon Corporation, Autometric Operation, Volume I, 1965, Volume II, 1965.

372 "Experimental Production of Military Geographic Intelligence Products from Side-Looking Airborne Radar Imagery," Final Report, Raytheon Corporation, Autometric Operation, March 1966, SECRET.

373 D. J. Bodnar, ETL-46-TR, "Use of Side-Looking Airborne Radar (SLAR) Imagery for Engineering Soils Studies," September 1969.

374 A. F. Pearson, ETL-ETR-70-10, "Military Geographic Intelligence Products Associated With the SLAR Topo Map Test in Panama, November 1970.

processor work being done by Hughes Aircraft Company for the U.S. Navy and the Air Force. The unique design of the Hughes processor permitted a wide range of signal processing variations not feasible or not tractable in a purely optical system. The report[375] showed the broad range of operations possible on radar signals from a wide variety of radars and suggested meaningful applications for interpretation and image enhancement. No further funding of this effort was forthcoming pending further development by ETL of the universal radar mapping correlator.

(7) **Radar Calibration.** As a result of initial studies of radar interpretation, the idea of calibration was defined as a prime requirement for quantitative and reliable radar interpretation. The idea of radar calibration was to determine all radar system and geometry parameters so that a scattering coefficient could be computed from a form of the radar range equation. Initial efforts in this direction were funded by ACSI through the Army Intelligence Agency, Fort Holabird. Their funds in turn were committed through a U. S. Air Force Project 665A to calibrate and test the AN/APS-73 (XH-4) radar in a controlled situation in the Phoenix, Arizona, area.

The radar calibration was completed by Goodyear Aerospace Corporation in September 1965, and flight tests were made from 15 October to 22 December 1965 and from 23 March to 28 April 1966. Following the flight tests ETL contracted with Goodyear[376] to reduce the flight data to scattering coefficients and determine whether or not a calibrated radar would aid an interpreter of radar imagery. The basic conclusion of this study was that the calibrated radar would aid the interpreter significantly in determining features of importance in military geographic analysis.

In-house analysis of the calibration techniques concluded basically that the Goodyear technique was valid if certain conditions were met[377] but that Goodyear had overlooked many parameters in its data-reduction analysis which were important to the calibration problem. A contract was then initiated with Westinghouse Electric Corporation in November 1969 to obtain a total definition of the calibration problem with particular emphasis on the AN/APQ-97 real aperture radar.[378] The contract provided a thorough derivation of the radar range equation for area targets and a basic systems methodology for calibrating the AN/APQ-97.

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375 "Optimum Intelligence Exploitation of Coherent Radar Signals," Hughes Aircraft Company, January 1967.

376 "Analysis of Radar Calibration Data," Final Report, Goodyear Aerospace Corporation, November 1967, Supplemental Report, May 1968.

377 R. A. Hevenor, ETL-43-TR, "A Mathematical Analysis of a Technique for the Calibration of a Synthetic Aperture Radar," November 1968.

378 "Radar Calibration Study," Final Report, Westinghouse Electric Corporation, February 1970.

(8) **Radar Scattering.** R. A. Hevenor started in-house studies to understand the parameters that affect the scattering of electromagnetic waves from rough terrain type surfaces in 1968. This study was initiated so that the results of radar calibration work might be more understandable and also to furnish design criteria for future side-looking radars.

At first, the problem of wave reflection was solved from a plane surface boundary dividing two homogeneous mediums. An analysis was then made of the effect of nonhomogeneous soil mediums on the reflected fields. Mathematical models were developed assuming continuous nonhomogeneity and discrete layered nonhomogeneity.

The results of these investigations were recorded in the form of a technical paper[379] which was accepted for the 1970 Army Science Conference at West Point, New York. Studies continued in 1969 and 1970 to develop the scattering of electromagnetic waves from rough surfaces more accurately.

(9) **Project THEMIS.** Project THEMIS was to furnish government support through the Defense Department to a limited number of universities not already funded on DOD projects. One of the 200 proposals selected for funding, based partly on the recommendations of Mr. Scheps of the Geographic Sciences Division staff who participated in proposal evaluation, was the proposal of the Center for Research, Inc., University of Kansas, Lawrence, Kansas, to establish a center of excellence for remote sensing. The proposal included work in developing broadband radar, analysis of radar imagery, pattern recognition, and selective display of photographic imagery for density slicing and analysis.

The Geographic Sciences Division was given the responsibility for preparing and monitoring the contract in August 1967. A contract was awarded in September 1967.

This program proved to be highly successful and produced high quality work. By 1970, five semiannual Interim Technical Progress reports[380] (containing 37 technical papers) had been published, and at least six doctoral dissertations had been produced on radar work, geologic, and geomorphological analysis of radar imagery, pattern recognition of terrain, image discrimination enhancement combining and

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[379] R. A. Hevenor, "A Mathematical Analysis of the Propagation and Reflection of Plane Electromagnetic Waves in a Non-Homogeneous Isotopic Medium.' See also R. A. Hevenor, ETL-RN-70-2, "A Relation Between the Spectrum of Surface Slopes and the Spectrum of Surface Elevations and Its Usefulness in the Theory of Electromagnetic Wave Scattering From Rough Surfaces," July 1970.

[380] "Project Themis: A Center for Remote Sensing," Kansas University, Progress Report, April 1968, Interim Report, October 1968, Interim Report, March 1969, Progress Report, September 1969, 5th Semi-Annual Report, March 1970.

sampling system, as well as geographic application of multi-image correlation remote sensing techniques.

The center also provided valuable advisory assistance on radar studies and published numerous technical reports in the related field of military geography.[381 - 388]

(10) Project SAND. In 1967, the Office, Chief of Engineers, requested the Geographic Sciences Division to provide scientific and technical assistance to the U.S. Army Waterways Experiment Station, Vicksburg, Mississippi, in investigating the use of remote sensor imagery for locating engineer construction materials in the Mekong Delta, Vietnam, in support of Project SAND. This project was initiated in response to a request for assistance from the Engineer, U.S. Army Headquarters in Vietnam, and was designed to be conducted in three phases.

Phase I was conducted by the Waterways Experiment Station in the summer of 1967. This phase was to determine the extent to which construction materials and sites could be located using existing photography and background literature. Several 1:250,000 scale map overlays were produced depicting the distribution of potential sources of sands and areas suitable for construction.

Phase II extended the results of Phase I through the use of more exotic types of remote sensors and techniques. The Geographic Sciences Division staff prepared a remote sensor package and detailed flight plan for acquisition of multisensor imagery over priority areas of the Mekong Delta. The flight program was conducted in April 1968. A team of scientists and engineers analyzed this imagery at Fort Belvoir in July 1968. It was determined that the primary sources of sand were the flanks of beach

[381] "The Bayesian Approach to Identification of a Remotely Sensed Environment," Kansas University, July 1968.

[382] Appendix II, "Narrative Report for Geoscience Analysis," Kansas University, August 1968.

[383] "The Frequency Dependence of Backscatter from Rough Surface (An Experiment With Broad Spectrum Acoustic Waves)," Interim Report, Kansas University, September 1968.

[384] "Interpretation of Radar Imagery for Terrain Analysis in Tropical Environments," Kansas University, October 1968.

[385] "Geologic Evaluation of Radar Imagery From Darien Province, Panama," Interim Report, Kansas University, June 1969.

[386] "The Apparent Temperature and Emissivity of Natural Surfaces at Microwave Frequencies," Kansas University, March 1970.
"Structural Analysis From Radar Imagery, Eastern Panamanian Isthmus," Kansas University, July 1970.

[387] "Broad Spectrum Electromagnetic Backscatter," Kansas University, August 1970.

[388] "Geomorphic Evaluation of Radar Imagery of Southeastern Panama and Northwestern Columbia," Kansas University, February 1971.

ridges and sand bars in river channels. Other potential sources of construction materials were identified.[389-391]

The Phase III flight test program was conducted during March 1969 over areas of the Mississippi Delta which contains similar land forms to those occupying the Mekong Delta. Five areas were identified for the flight tests based on the known occurrence of surface and subsurface sand and gravels. Through correlation of these known occurrences with their remote sensor reponses, the relative performance of each sensor could be evaluated.

Again, a team of earth scientists and engineers was assembled, this time at the U.S. Army CRREL during 18 to 29 August 1969 to analyze the remote sensor imagery. This team reassembled at CRREL during 15 through 18 September 1969 to consolidate their observations, evaluation, and results. Geographic Sciences Division personnel compiled the report in April 1970 describing the approach, procedures, and results of the Phase III study.

The approach to locating sources of construction materials using remote sensor imagery involved two basic analytical steps: (1) study of broad regional geographic and physiographic patterns to delineate the land forms having the highest potential as sources of the desired materials, and (2) study of the selected land forms in detail to assess the characteristics of materials of which they are composed. Small scale imagery provided the synoptic view, and large scale imagery was required for the detailed analysis.

The results of these investigations[392, 393] were well received by the military engineers and the scientific community in general.

In addition to these investigations and supplements to them, an analysis of multispectral scanner data for location of sand and ground deposits was made under contract by the Bendix Corporation, Ann Arbor, Michigan.[394]

389 "Project SAND - Availability of Construction Materials in the Mekong Delta," Kansas University Technical Memo 156-1, August 1968.

390 D. G. Orr and J. R. Quick, "Project SAND—Remote Sensing for Engineer Construction Materials," Presented at ASP-ACSM Convention, Washington, D. C., March 1970.

391 D. G. Orr, ETL-52-TR, "Remote Sensor Imagery Analysis for the Location of Construction Materials in the Mekong Delta," Project SAND (Phase II), January 1970.

392 "Report on Project SAND," Presented at DIAMC Meeting, Cameron Station, Alexandria, Virginia, October 1969.

393 D. G. Orr and J. R. Quick, "Project SAND—Remote Sensing for Engineer Construction Materials," Presented to ASP-ACSM Annual Convention, March 1970.

394 "Analysis of Multispectral Scanner Data for Location of Sand and Ground Deposits," Final Report, Bendix Corporation, January 1970.

(11) Automatic Image Data Extraction. Early in its existence, the Geographic Sciences Division started investigations directed toward the automatic or semi-automatic detection, recognition, extraction, and symbolization of military geographic information from aerial photography. These investigations led to the development of a study plan titled "Automated Image Data Extraction System" (AIDES).

One of the first efforts in these investigations was the problem of change detection in photographic imagery. This effort led to the production of a prototype model change detector by the Goodyear Aerospace Corporation. This prototype was completed and delivered in 1965.[395] [396] Concurrently, studies were made by Scope, Inc., under contract on the application of Learning Machine, Conflex 1.[397] These studies were extended for a design study for application in a mapping device.[398]

The main efforts of the study plan for the automated image data extraction system centered about the Natural Image Computer (NIC)—a prototype pattern recognition system. This device was originally envisioned as a fully optical system using film masking and photographic grey level filtering and clipping techniques for performing image data extraction experiments. On analysis, it was decided that a digital computer-based system, capable of generating and applying these masks and pattern recognition logic, would allow simulation of the principle with greater flexibility.

A contract was awarded to Aeronutronics Division of Philco-Ford Corporation in 1964 for the design, fabrication, and system study of a prototype NIC, including testing of the system and development of software to identify and extract mapping features such as orchards, woods, lakes, oil tanks and railroad yards.[399] The NIC hardware was delivered in April 1967 (Fig. 173).

In-house testing of the NIC was completed in November 1968.[400] It was concluded that the NIC was acceptable for performing pattern recognition experiments although improvements in hardware and software were needed. Because of the lengthy digital (serial) processing time required by the NIC, the development of an

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395 J. R. Shepard, "A Concept of Change Detection," Presented at the ASP-ACSM Annual Convention, 1964.

396 "Development of an Evaluation Model Change Detector," Final Report, Goodyear Aero Space Corporation, November 1965.

397 "Cartographic Application of CONFLEX 1," First Interim Report, Scope, Inc., Falls Church, Virginia, November 1964.

398 "MAPCON Design Study," Final Report, Scope, Inc., May 1967.

399 "Natural Image Computer," Final Report, Volumes I and II, Philco-Ford Corporation, Aeronutronics Division, April 1967.

400 L. P. Murphy, ETL 48-TR, "Evaluation of the Prototype Natural Image Computer," November 1969.

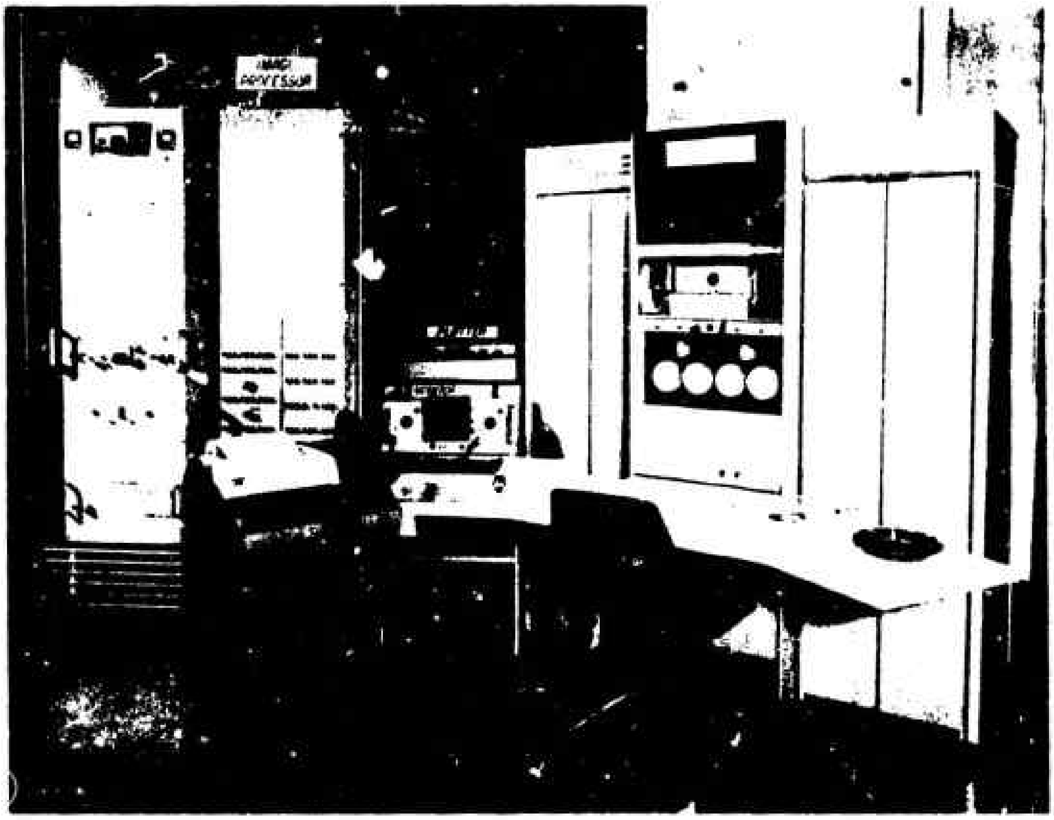

Fig. 173. Natural Image Computer (NIC).

operational system based on this concept could evolve only through long-range development and perhaps returning to parallel processing made of operations as in the original concept.

As an interim system goal, consideration was given in 1967 to the development of an analog processing device called the Image Display, Enhancement and Combining System (IDECS). This idea originated at the CRES Laboratories of the University of Kansas. Funding for the development of the IDECS device was from NASA, THEMIS funds, and an ETL contract for a system study.[401] The IDECS device allows synchronous scanning of whole photographs by four input scanners, grey level clipping in each channel, combination of the results, and electronic display in color and black and white. The device permits the operator to produce false color enhancements of the images and clip and display selected features from multisensor image inputs. Unlike the NIC, the IDECS allows the operator to interact rapidly and perform the decision-making

[401] "Multi-Image Correlation System Study for MGI," University of Kansas, Phase I Report, December 1967, Phase II Report, June 1968, Final Report, December 1968, Supplement to Final Report, September 1969.

process within the system. In 1970, the acquisition of an improved prototype IDECS was planned.

In 1969, a re-evaluation of the change detector device was made. On original evaluation in 1965, this device was found to have severe operational restrictions in correlation of images flown at different times, altitudes, and formats. The re-evaluation recommended that the change detector be modified to perform in-house correlation analysis studies in the application of marking functions for the classification of topographic features.[402]

Finally, there was one other investigation related to change detection that was made in the 1964 to 1965 period. This study investigated the potential of change detection as applied in a map revision device using orthophoto inputs. All configurations designed to meet the imposed requirements were found too complex and expensive. In effect, the stereoplotter[403] was re-invented and further development was terminated.

(12) Automated System for Handling Military Geographic Information. The Corps of Engineers and GIMRADA became involved in the development of an automated system for handling military geographic information in 1963 when the Combat Developments Command requested that the Corps of Engineers provide assistance in the field of terrain intelligence. In March 1965, Combat Developments Command provided $140,000 and requested that GIMRADA make a study with the title "Terrain Intelligence Input to the Intelligence System of the Command Control Information System – 1970 (CCIS-70)."

Because of personnel shortage, it was necessary to contract the job, so in September 1965 a contract was awarded to the Federal Systems Division of the International Business Machines Corporation for a "Study of Engineer Intelligence and Terrain Intelligence Functions in Military Operations."

The first draft of this study was delivered in September 1966, and since it did not go far enough to satisfy the real requirement, the contract was modified in October 1966 under the new title "Terrain Intelligence Input to the Tactical Operation System (TOS) of the Automatic Data System Within the Army in the Field (ADSAF)."

The study was completed in November 1967.[404] The major

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[402] E. G. Trelinski, Jr., "Evaluation of Change Detector for Research," Technical Memorandum, October 1969.

[403] "Orthophoto Viewer and Transfer Device," Final Report, Goodyear Aerospace Corporation, June 1965.

[404] "Terrain Intelligence Input to the Tactical Operations System (TOS) of Automatic Data Systems Within Army in the Field," Final Report, International Business Machines Corporation, Volumes 1 through 6, July 1967.

recommendation was the establishment of a separate Engineer Terrain Information System (ENTIS) to support TOS. Combat Developments Command approved the recommendation.

Following this, work started within ETL to refine the information needs cited in the IBM report. A plan was designed to develop ENTIS and a counterpart system for use above field Army level called the "CONUS System for Terrain Information (CONSTIN)." It was proposed to concentrate initial efforts on CONSTIN under the advanced development project on military geographic systems, while staffing of the IBM study was in progress; but, unfortunately, through a series of administrative miscues at Department of the Army, funds for the project were not approved until April 1969.

Meanwhile, the Department of the Army was considering a project to study the mapping information needs and to design a Field Army mapping system. Since MGI and mapping are interrelated, it was decided that a single study should be done to tie all the Field Army topographic aspects together. This study titled "Geographic Intelligence and Topographic Support for the Army in the Field" (GIANT) was implemented by the Combat Developments Command in September 1968. It included studies related to the 1970 to 1975 time frame and also the 1975 to 1985 time frame (GIANT-75 and GIANT-85).

These studies were designed to address the critical area of user needs for topographic data by analyzing the nature of military problems which require such data for solution. Upon determination of the nature, timeliness, degree of accuracy, and application of the data, formats most suitable for presentation of the data for various uses were to be established to form the basis for developing systems including new organizational and equipment concepts. The studies were also to consider the interrelationship between field mapping and geodesy and MGI systems and supported systems, such as the TOS and TACFIRE as well as the relationship between the field and supporting systems including a data bank.

In 1970, the GIANT study was being staffed through Department of the Army channels, and the ENTIS effort remained in limbo. In the meantime, in May 1969, the Geographic Sciences Division enlisted the aid of the Engineer Agency for Resources Inventories, Military Geology Branch of the U.S. Geological Survey, and the Waterways Experiment Station and started work on the development of MGI data base. By 1970, an initial data base index had been prepared, input formats for both manual and machine operations were being designed, analytical models for computer application were being tested, hardware for an experimental system was being evaluated, test sites were being selected for future uses, and concepts for handling raw data were being devised. A revised advanced development plan for the project was submitted in February 1970.

(13) **MGI Products Development.** A TOPOCOM directive of 28 April 1969 approved the initiation of work to develop a prototype family of MGI products designed to meet the needs of an Airmobile Division. Mr. A. R. Pearson of the Geographic Sciences staff organized a project team which included personnel from collaborating agencies, Engineer Agency for Resources Inventories (ARIE), Military Geography Branch, USGS, and Waterways Experiment Station.

By November 1969, prototype products were produced and a draft technical report was completed by January 1970.[405] The three prototype products were: an air movement product designed to support movement of airmobile forces from the staging area to the vicinity of the landing zones; an air landing product designed to support the landing and liftoff phases; and a ground tactical product designed to support the ground tactial phase of the operation. The report included a recommended production outline which was considered a significant step in upgrading the capabilities of engineer terrain detachments by providing a production concept that will permit the detachments to improve the quality and reaction time of their products.

In 1970, it was planned to develop other prototype products to support military operations such as infantry, armored, and amphibious.

(14) **Reserve Unit Activities.** In 1968, the Geographic Sciences Division implemented a program of affiliation of U.S. Army Reserve units with the Engineer Topographic Laboratories for training purposes. This program was to provide meaningful training for the reserve units to enhance their capabilities and also to accomplish critical phases of the geographic sciences program that had not been initiated because of manpower shortages.

In September 1968, the 401st Military Intelligence Detachment was assigned and given a project to analyze those sections of the National Intelligence Survey that deal with military geography, make a tabulation of data requirements and their precision measurements for 44 MGI data elements, and determine the specific military and engineering functions which established the requirements. This unit performed its yearly active duty training at ETL and held its monthly drills in the Geographic Sciences Division area. This unit completed its original project in January 1970 and was then tasked to develop an urban area file for the Fort Belvoir data base.

In March 1969, the 442nd Military Intelligence Detachment was assigned and given a project to evaluate various types of remote sensor imagery to determine the suitability of each to yield imagery interpretation intelligence data concerning

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[405] A. R. Pearson and Others, ETL-ETR-70-7, "Development of a Prototype Family of Military Geographic Intelligence Products to Support Air Mobile Operations," August 1970.

certain aspects of the terrain which influence military operations. This unit also performed its annual active duty training at ETL. It was scheduled to complete its original project by September 1970 and at that time was to be assigned a project in support of selection and development of MGI test sites.

In April 1969, the 334th Engineer Detachment (Terrain), Nashville, Tennessee, was assigned and tasked with the preparation of dossier overlays for part of the Fort Belvoir data base. This unit also performed its annual active duty training at ETL.

Also, in April 1969, the 572nd Mobilization Designee Detachment, Denver, Colorado, became affiliated with ETL through assignment of specific projects to individuals of the detachment. In 1969 and 1970, COL Robert Cadigan performed active duty training at ETL on a project to conduct an experiment in multivariate statistical approaches to terrain intelligence parameters with the objective of finding ways to make broad objective reproducible regional classifications.

In March 1970, the 462nd Military Intelligence Detachment was assigned to ETL and tasked to analyze MGI data base listings, precision requirements and cross-referencing demands, and to develop a general system design to develop software for the MGI experimental system.

Finally, the 378th Engineer Detachment (Terrain) was scheduled for assignment in September 1970 and was to be assigned a project in support of the selection and development of MGI test sites.

This program provided valuable assistance to the Geographic Sciences staff in areas not previously covered as well as meaningful training of reserve unit personnel in their military specialties.

(15) On-The-Job Training of Graduates of the Terrain Analysts Course. In 1968, a program to provide the graduates of the Terrain Analysts Course of the U.S. Army Engineer School with an opportunity to make practical application of their training on projects typical of those that the students would encounter in their permanent assignments was implemented when ETL agreed to conduct three such on-the-job training courses beginning in August 1968. The first class of 10 students was placed on temporary duty with ETL for 7 weeks in August 1968, the second class of nine students in December 1968, and the third, and final class, joined ETL in June 1969.

Through this progrm, Terrain Detachments and Area Analysis Offices received trained personnel with some degree of experience, thus improving the competence of terrain intelligence producing organizations.

(16) **Status of Military Geographic Analysis Programs at FY 70.** In addition to the above-noted research activities, studies and programs related to the development of advanced integrated MGI systems and several other significant investigations and reports were made which have not been noted previously.

In 1967, Technical Operations, Inc., completed a study on reduction and classification of the data base list;[406] Spartan Air Surveys Limited, Ottawa, Canada, completed an evaluation of land-use techniques for processing MGI;[407] the Sperry Rand Corporation completed a study on a systems concept for MGI;[408] and ETL published a technical report on a methodology for military geographic analysis.[409]

In 1969, two additional studies and reports were completed. The Ohio State University Research Foundation completed a study on the geographic modeling of insurgency resources in February 1969,[410] and in December 1969 the Florida Atlantic University, Department of Geography, completed a review of new geographic methods and techniques.[411]

By 1970, the work on the analysis of MGI requirements and the definition of system concepts had progressed to the point where MGI requirements had been obtained from all sources (FMs, TMs, system and operation analysis) and had been verified through field trips to Europe and Vietnam, providing input to the advanced development of various prototype MGI products. The data requirements had been organized into data fields to provide the basis for data base organization in advanced systems development. Preparations were in progress to implement the GIANT study recommendation. The study to modernize the engineer terrain detachment equipment assemblage was nearing completion with the preparation of an SDR. Work was underway on the selection of MGI test sites. Project SAND was in the final stages of completion, and technical assistance was being provided TOPOCOM to meet new production requirements.

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406 "Reduction and Classification of the Data Base List," Final Report, Technical Operations, Inc., Hampton, Virginia, May 1967.

407 "Evaluation of Land Use Techniques for Processing MGI," Final Report, Spartan Air Service Limited, June 1967.

408 "Systems Concepts for Military Geographic Intelligence," Final Report, Volumes I and II, Sperry Rand Corporation, UNIVAC Defense Systems Division, June 1967, SECRET.

409 R. A. Leestma, ETL-TR-6, "A Methodology for Military Geographic Analysis," August 1967.

410 "The Geographic Modeling of Insurgency Resources," Final Report, Ohio State University Research Foundation, February 1969, Appendix, April 1969.

411 "Review of New Geographic Methods and Techniques," Final Report, Florida Atlantic University, Department of Geography, Volume I, December 1969, Volume II, October 1969.

The work on MGI data collection in 1970 was at the point where contracts had been awarded for an experimental multiband camera system and a color corrected camera. Plans were being made for flight testing to be initiated early in FY71. Work on radar and radar calibration was continuing under contract to Westinghouse to obtain expert theoretical radar support for ETL engineers engaged in the definition of APQ-97 radar calibration technique. Plans were being made to calibrate the APQ-97 and to conduct a thorough test program. Also, the Waterways Experiment Station, through transfer of funds, was applying its expertise on studies to broaden the basic understanding and knowledge of the interaction of the terrain and the radar signal to support future development of multifrequency, side-looking radar. The MGI requirement for the Phase II mapping radar was scheduled for completion in FY70.

Work on MGI data reduction had progressed to the point where, by FY 70, studies by the University of Kansas on multi-image correlation were completed, producing a breadboard instrument for comparing various kinds of imagery to discriminate and enhance selected terrain features. Plans were being made to procure a prototype Image Discriminating Enhancing Correlating System (IDECS) which, in conjunction with the work with the Natural Image Computer, will provide the basis for developing the capability to automate many of the photo interpretation features at some future date. Remote sensor interpretation techniques had been developed. Pattern recognition studies by CRREL were scheduled for completion and new studies were to be initiated to develop quantitative analytical procedures for extracting terrain information from remote sensor imagery as well as theoretical studies on recognition of terrain features. An in-house investigation of the overall data reduction problem associated with MGI processing was initiated.

Under the MGI product and analysis definition task, by 1970 experimental products associated with the side-looking radar map test in Panama had been completed;[412] MGI products for airmobile operation had been completed; work was underway to design MGI products for infantry operations; and work was in progress at Waterways Experiment Station on a survey of existing terrain models and evaluation of their MGI applicability.

On MGI data handling by 1970, an experimental data base structure had been basically designed and in-house work had been initiated to investigate off-the-shelf computer hardware and other peripheral equipment required to establish operation of an experimental data base.

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[412] A. R. Pearson, ETL-ETR-70-10, "Military Geographic Intelligence Products Associated With the SLAR Topo Map Test in Panama (U)," November 1970, CONFIDENTIAL.

(17) **Status of Project for Advanced Development of MGI Systems at FY 70.** Work on the advanced development of the military geographic systems project until 1970 had been limited primarily to the development of terrain data products and the development of an experimental data base for automatic storage retrieval and analysis of MGI information. The development of some classified terrain analysis products, air mobile division products and prototype products to support mechanized infantry operation were completed by FY 70 and were being evaluated. Compilation of a Map Symbol Catalog was in progress at the Military Geographic Branch of U. S. Geological Survey. Phase I of the MGI data base organization effort, involving identification of each of the information needs for describing each data field was completed, and work started in Phase 2, the development of precision requirements for information needs. Work was nearing completion at Waterways Experiment Station on automation of a sample terrain model and at ETL on the selection and acquisition of MGI test sites.

VII. CONCLUSIONS

In a sense, the history of the Engineer Topographic Laboratories is also a history of the development of surveying and mapping over the past 50-year period. It is fair to say that for nearly all of the advances in technology in these areas, the Engineer Topographic Laboratories or one of its predecessor organizations was either the leader or served as a catalytic agent to stimulate and expedite the development process.

While there were many outstanding accomplishments in the technologies of surveying and mapping, there were also many disappointments, and the accomplishments were not made without some false starts and some misdirected efforts. But this is a part of the price which must be paid where new ground is being broken, and it is not possible to see clearly a sufficient distance down the road to predict the ultimate outcome accurately.

In the period covered by this history, U. S. Army's research and development activity in the surveying and mapping fields has grown from practically no activity at all at the close of World War I to a multi-million dollar activity, employing more than 200 persons on the ETL staff and many other personnel on the staffs of commercial organizations under contract to ETL. We have seen the technology advance virtually from transit and tape surveying and plane table mapping to the highly sophisticated systems involving advanced electronics and electronic ranging, inertial navigation technology, the most advanced computer technology, digital computer controlled automated mapping systems, automated storage cartographic and display systems, and information dissemination. With these developments, surveys can now be made spanning large distances and in a short time, topographic data for vast areas can be produced at remarkably high rates of production, and these data can be disseminated to the user in new and more readily understandable formats in a short period of time.

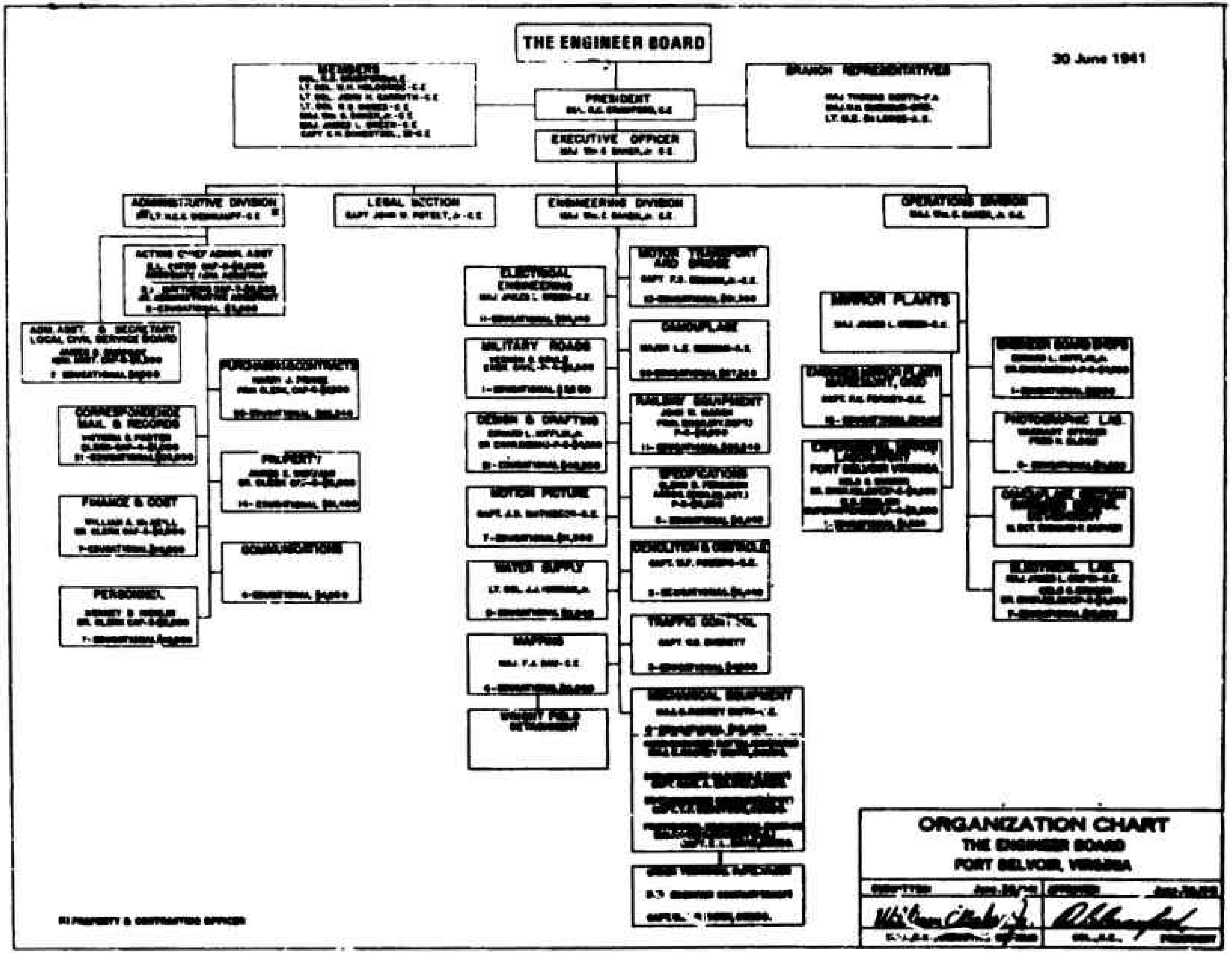
As remarkable as these developments have been, even more remarkable developments can be anticipated for the future. The surface has barely been scratched in the application of laser technology to the solution of surveying and mapping problems including high-density storage and readout. The application of advances in computer technology will no doubt revolutionize the mapping, data storage, and data dissemination concepts and systems through the application of digital techniques to these problems. Radar, color photography, and multi-spectral techniques of data sensing will no doubt effect major changes in concepts of data collection, interpretation, and processing. In the surveying and geodesy area, we can expect further refinement of position-determining systems including advanced applications of inertial systems. New systems of reproduction including one-step color can be expected to provide greatly simplified means for reproducing color imagery from full color orthophotomaps produced by automated mapping systems.

In anticipation of these advances, surely, it can be said that the past is merely prologue and that building on the solid foundation of the past developments of the future will no doubt be even more revolutionary than those of the past 50-year period.

APPENDICES

APPENDIX A

ORGANIZATION CHARTS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BRANCH REPRESENTATIVES
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ADMINISTRATIVE DIVISION
LEGAL SECTION
ENGINEERING DIVISION
OPERATIONS DIVISION
ELECTRICAL ENGINEERING
MILITARY ROADS
DESIGN & DRAFTING
MOTION PICTURE
WATER SUPPLY
MAPPING
MOTOR TRANSPORT AND BRIDGE
CAMOUFLAGE
RAILWAY EQUIPMENT
SPECIFICATIONS
TRAFFIC CONTROL
MECHANICAL EQUIPMENT
MIRROR PLANTS
PHOTOGRAPHIC LAB.
ELECTRICAL LAB.
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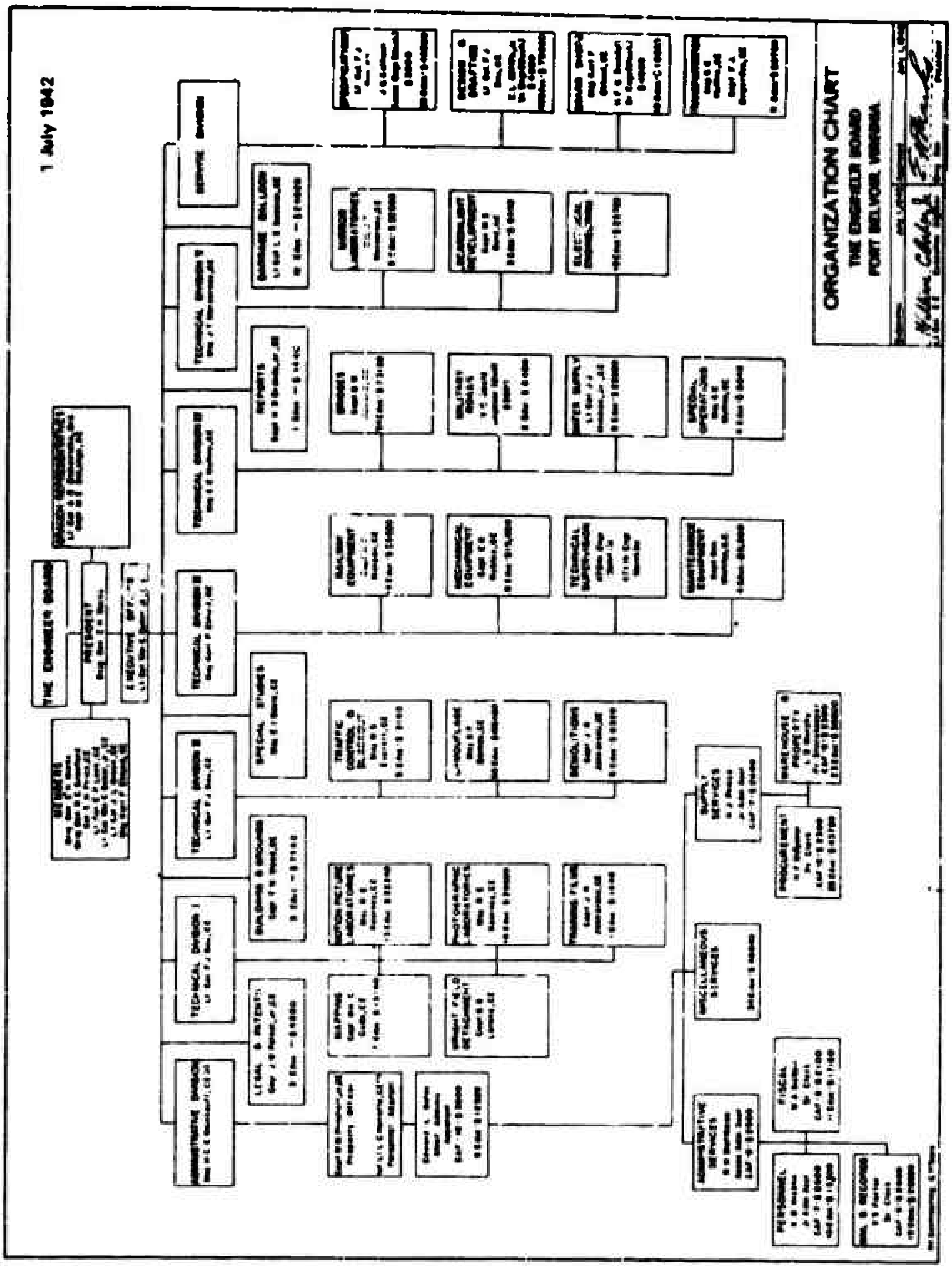
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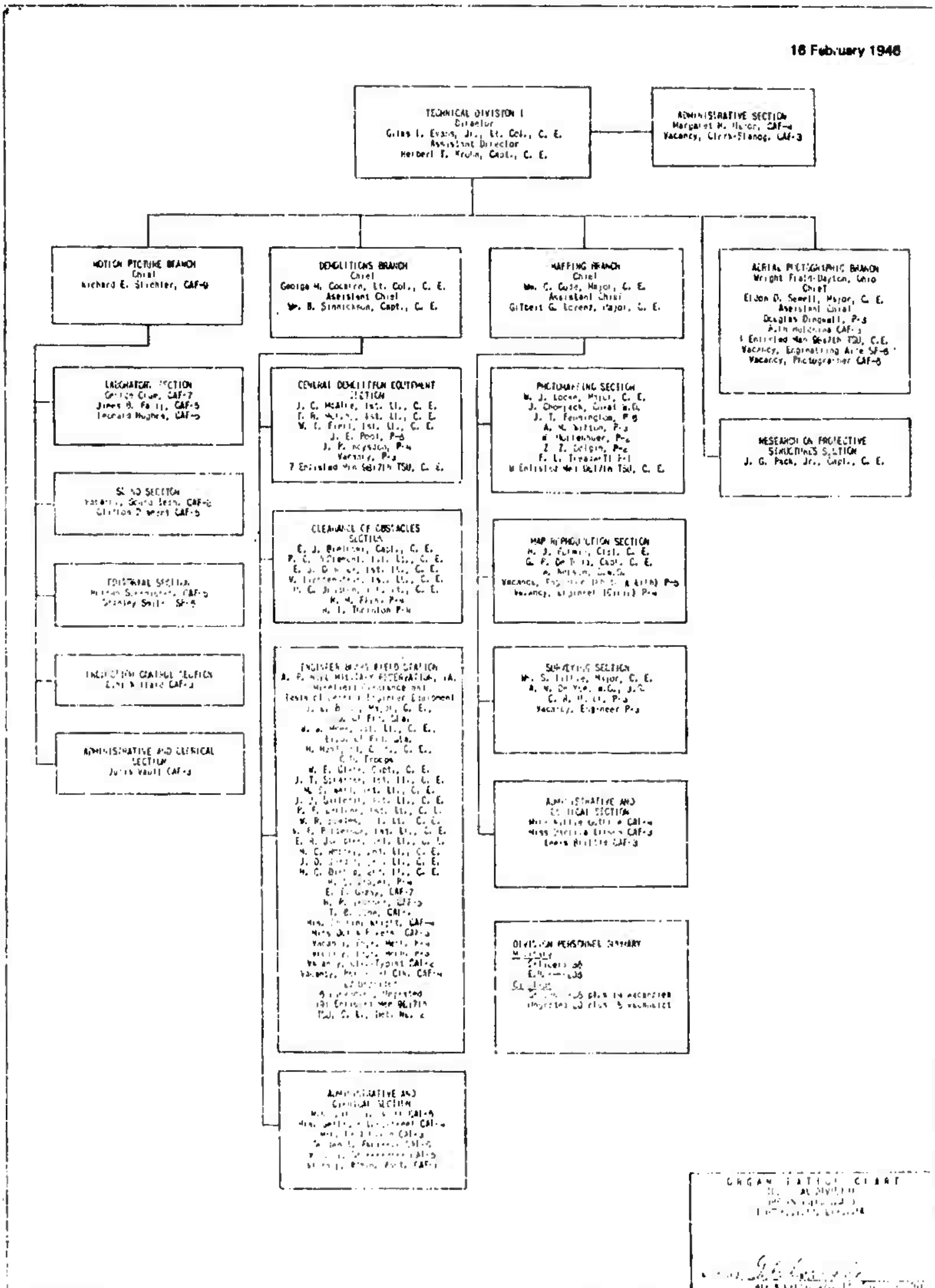
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Director
Giles L. Evans, Jr., Lt. Col., C. E.
Assistant Director
Herbert T. Kroha, Capt., C. E.
ADMINISTRATIVE SECTION
Vacancy, Clerk-Stenog. CAF-3
MOTION PICTURE BRANCH
Chief
Richard E. Stichler, CAF-9
DEMOLITIONS BRANCH
Chief
George H. Cochran, Lt. Col., C. E.
Assistant Chief
Wm. B. Sinnickson, Capt., C. E.
MAPPING BRANCH
Chief
Assistant Chief
AERIAL PHOTOGRAPHIC BRANCH
Wright Field-Dayton, Ohio
Chief
Eldon D. Sewell, Major, C. E.
Assistant Chief
Douglas Dingwall, P-3
Vacancy, Photographer CAF-6
LABORATORY SECTION
GENERAL DEMOLITION EQUIPMENT SECTION
PHOTOMAPPING SECTION
RESEARCH ON PROTECTIVE STRUCTURES SECTION
J. G. Pack, Jr., Capt., C. E.
SOUND SECTION
EDITORIAL SECTION
CLEARANCE OF OBSTACLES SECTION
MAP REPRODUCTION SECTION
PRODUCTION CONTROL SECTION
ENGINEER BOARD FIELD STATION
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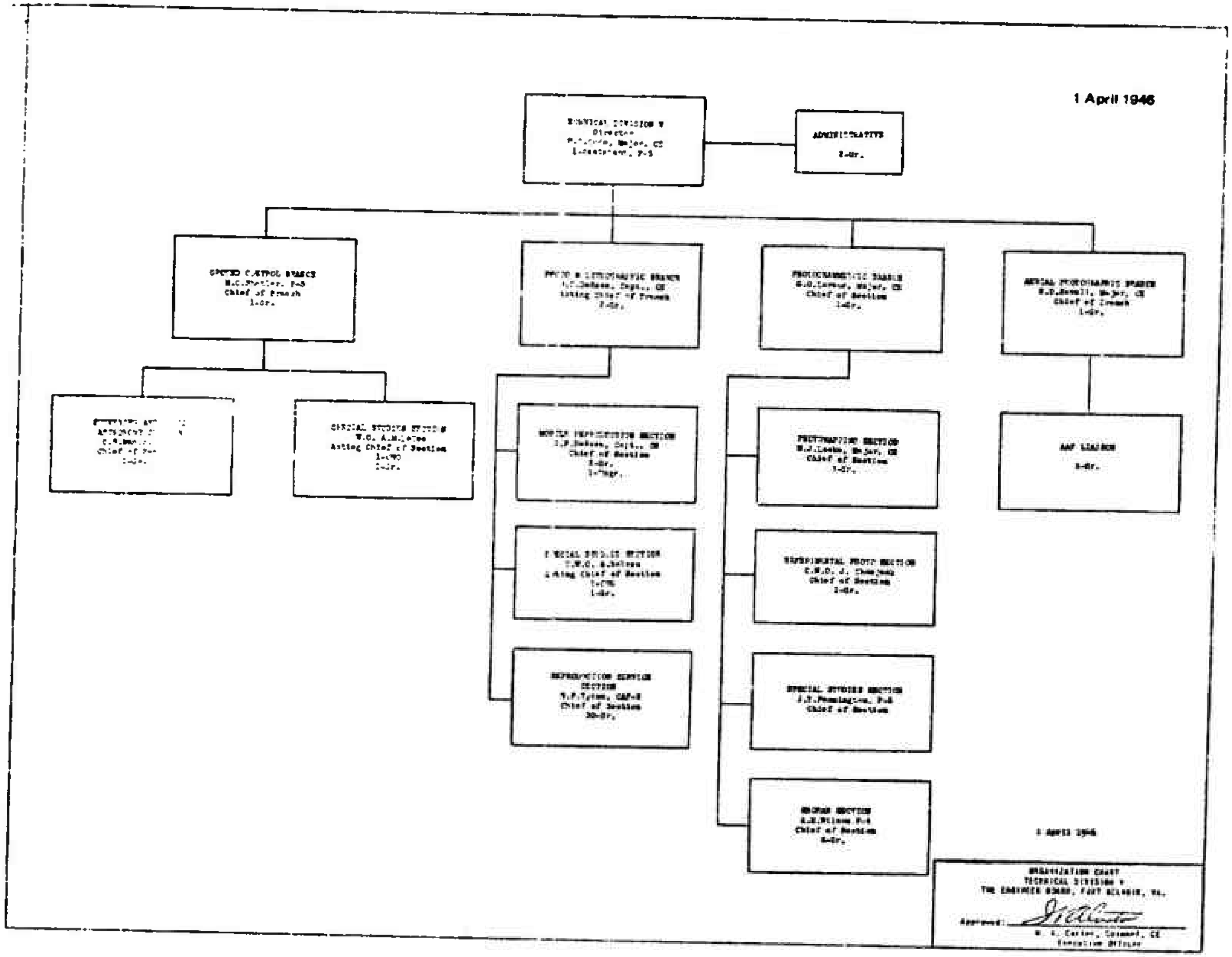
ADMINISTRATIVE AND CLERICAL SECTION
ORGANIZATION CHART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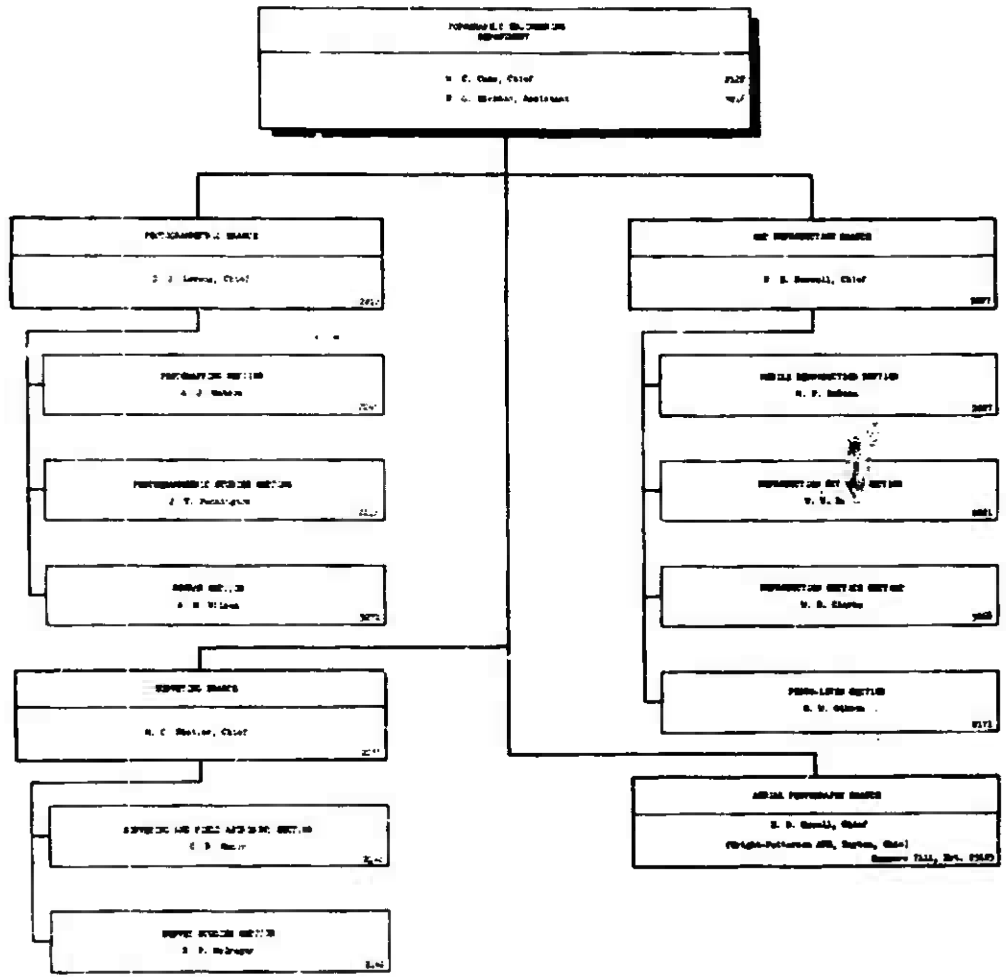
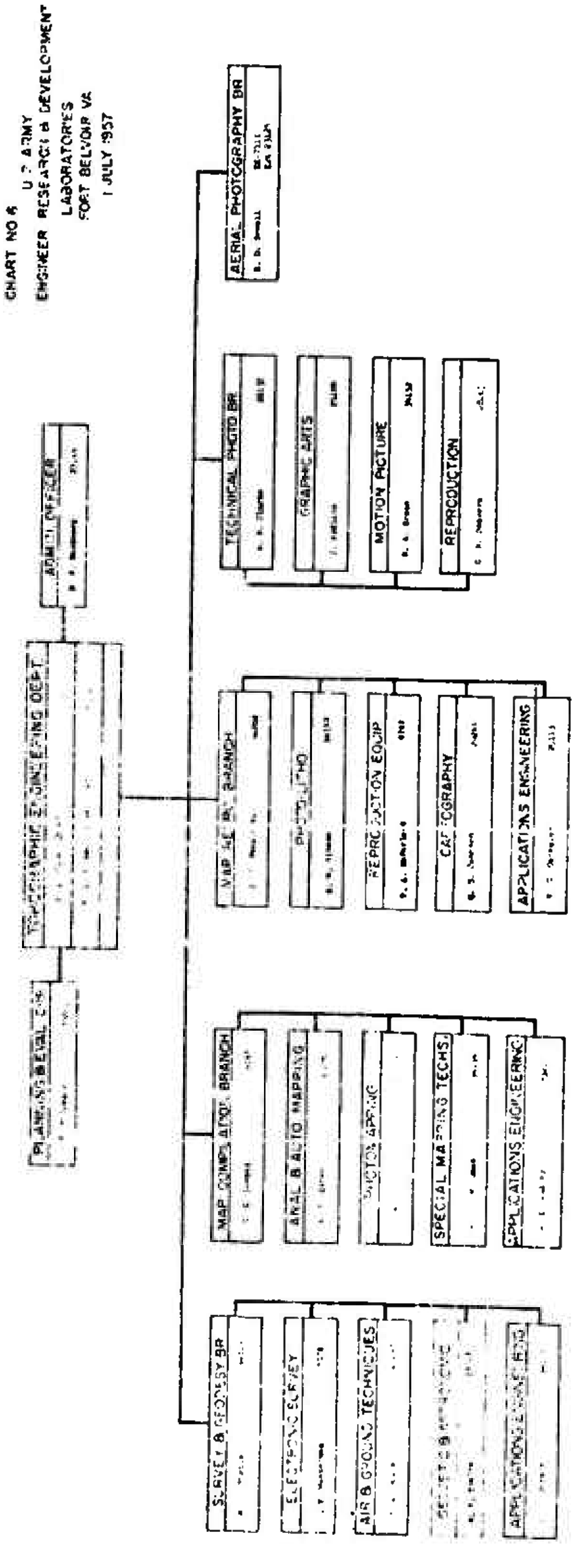
THE ENGINEER BOARD
FORT BELVOIR, VIRGINIA

ENGINEER
RESEARCH & DEVELOPMENT
LABORATORIES

1 January 1961

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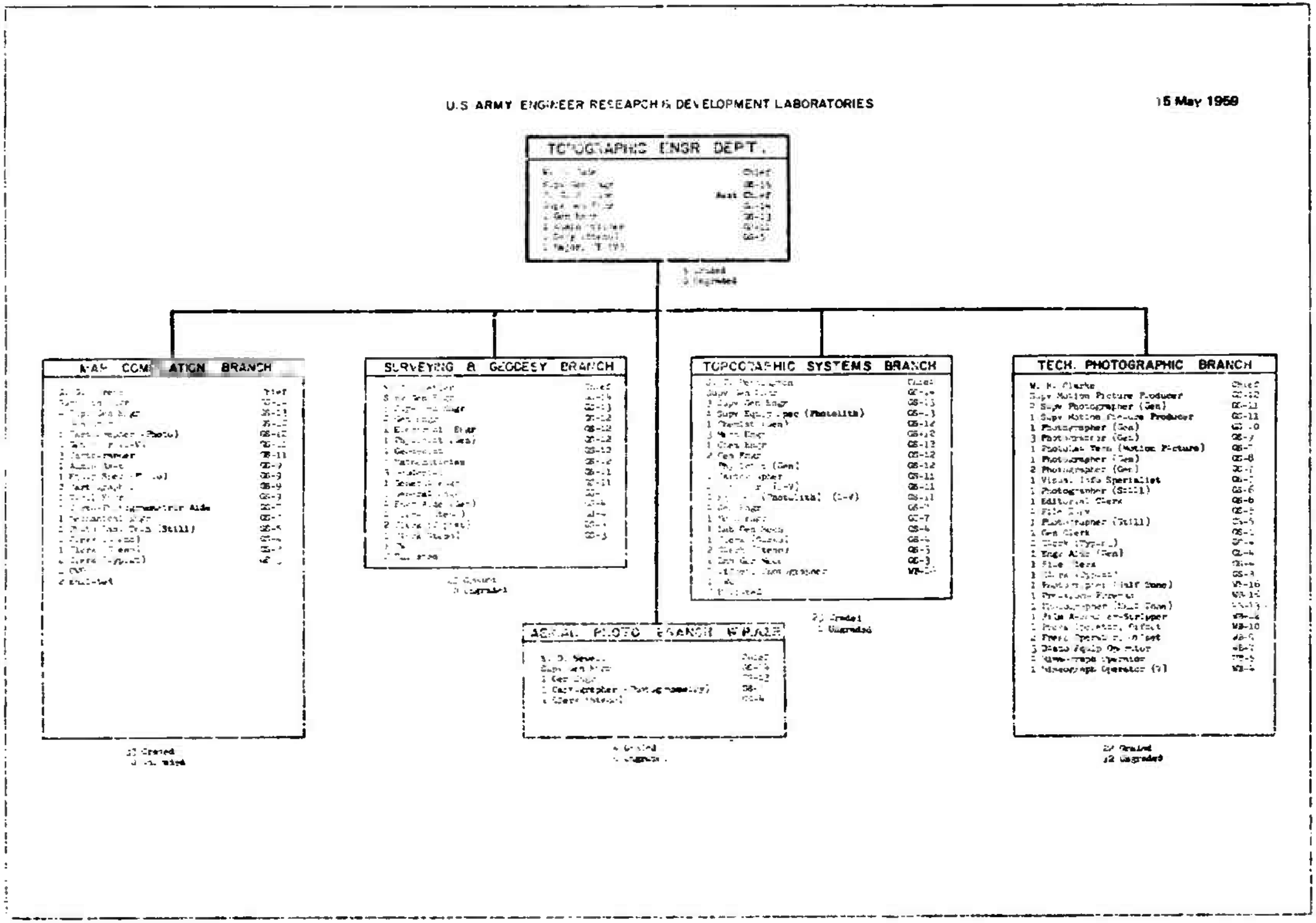
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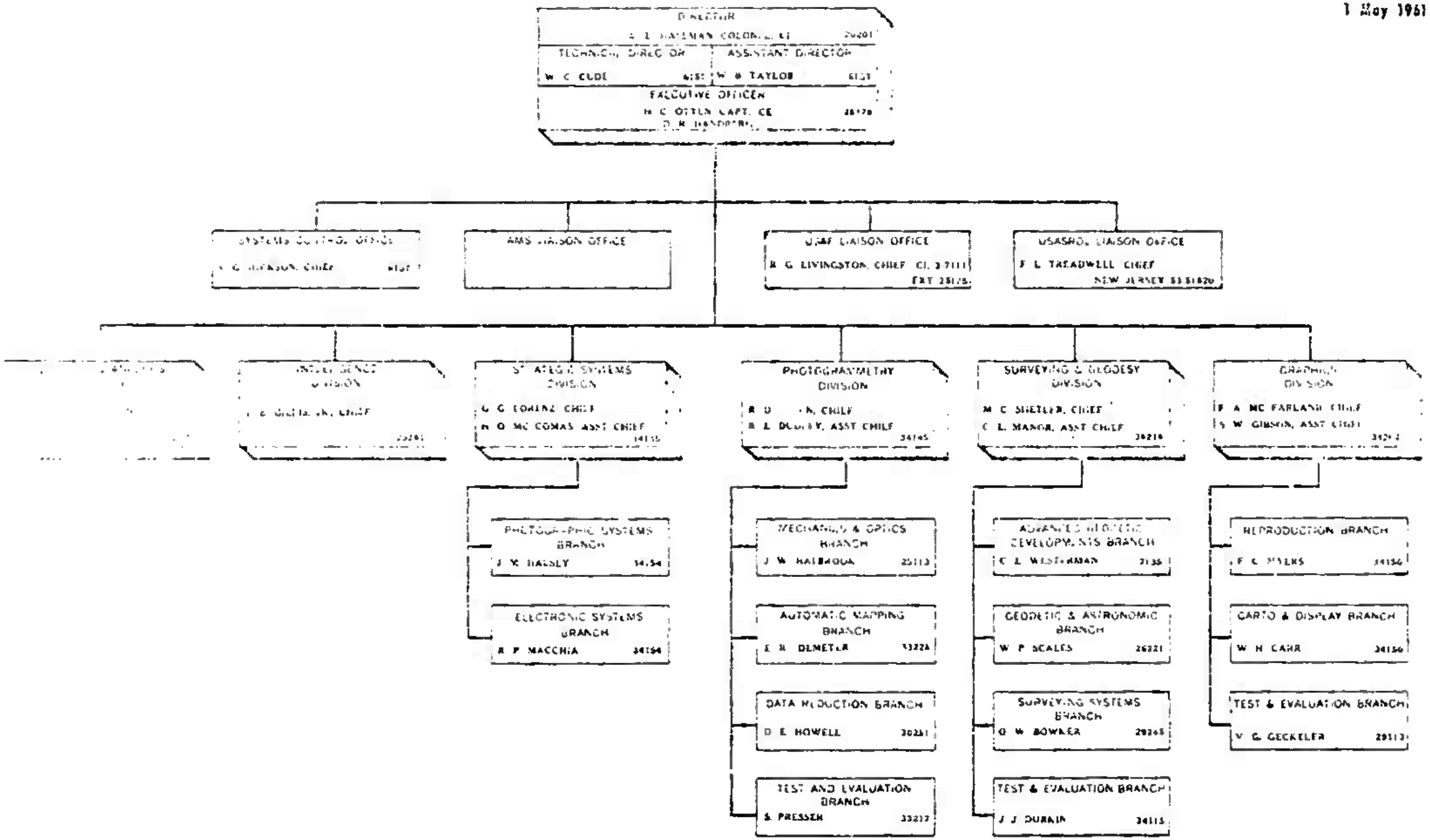
TOPOGRAPHIC SYSTEMS BRANCH
TECH. PHOTOGRAPHIC BRANCH
AERIAL PHOTO BRANCH W.P.A.F.B.

U. S. ARMY ENGINEER GEODESY, INTELLIGENCE AND MAPPING RESEARCH AND DEVELOPMENT AGENCY

FORT BELVOIR, VIRGINIA

1 May 1961



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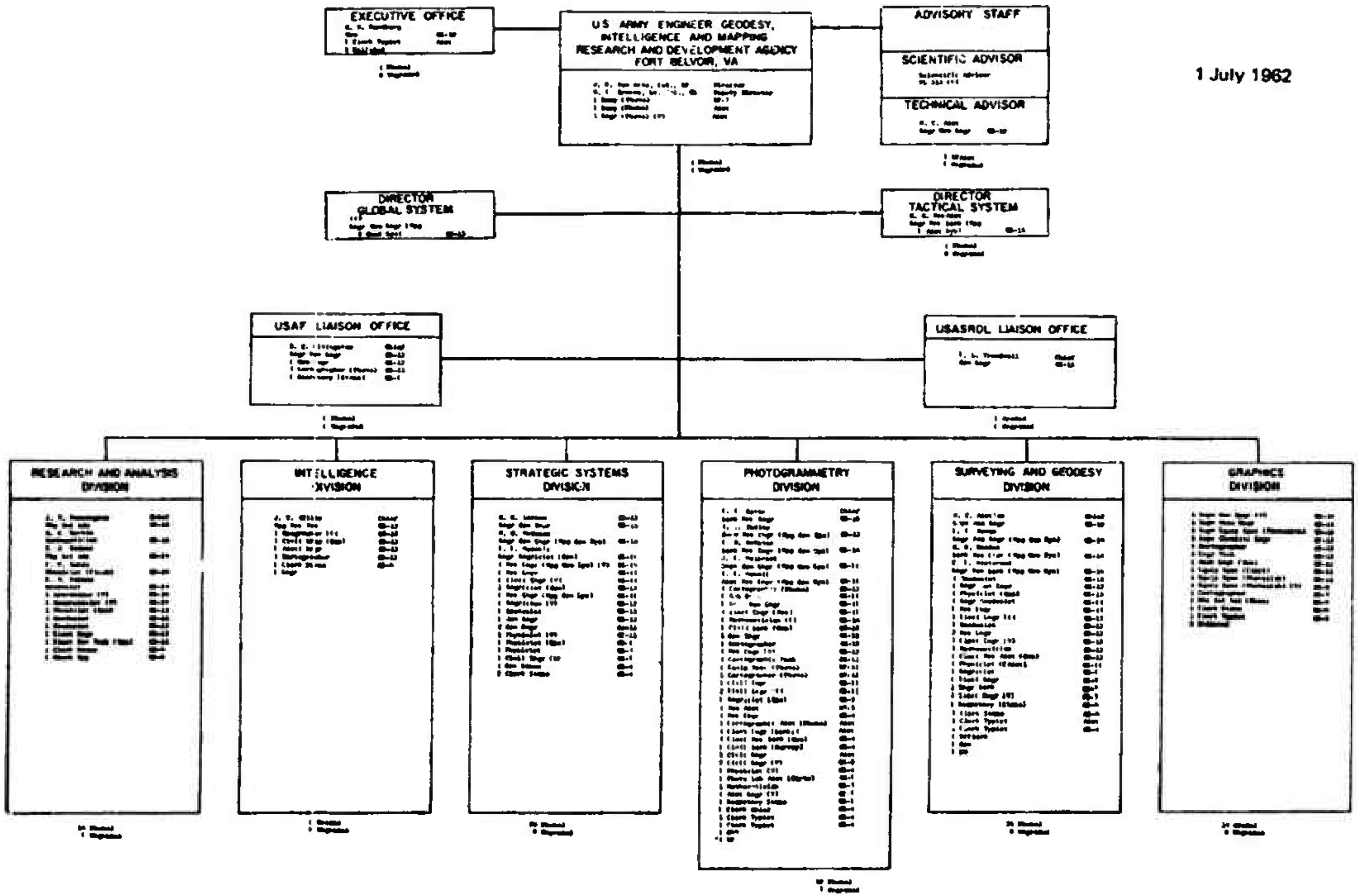
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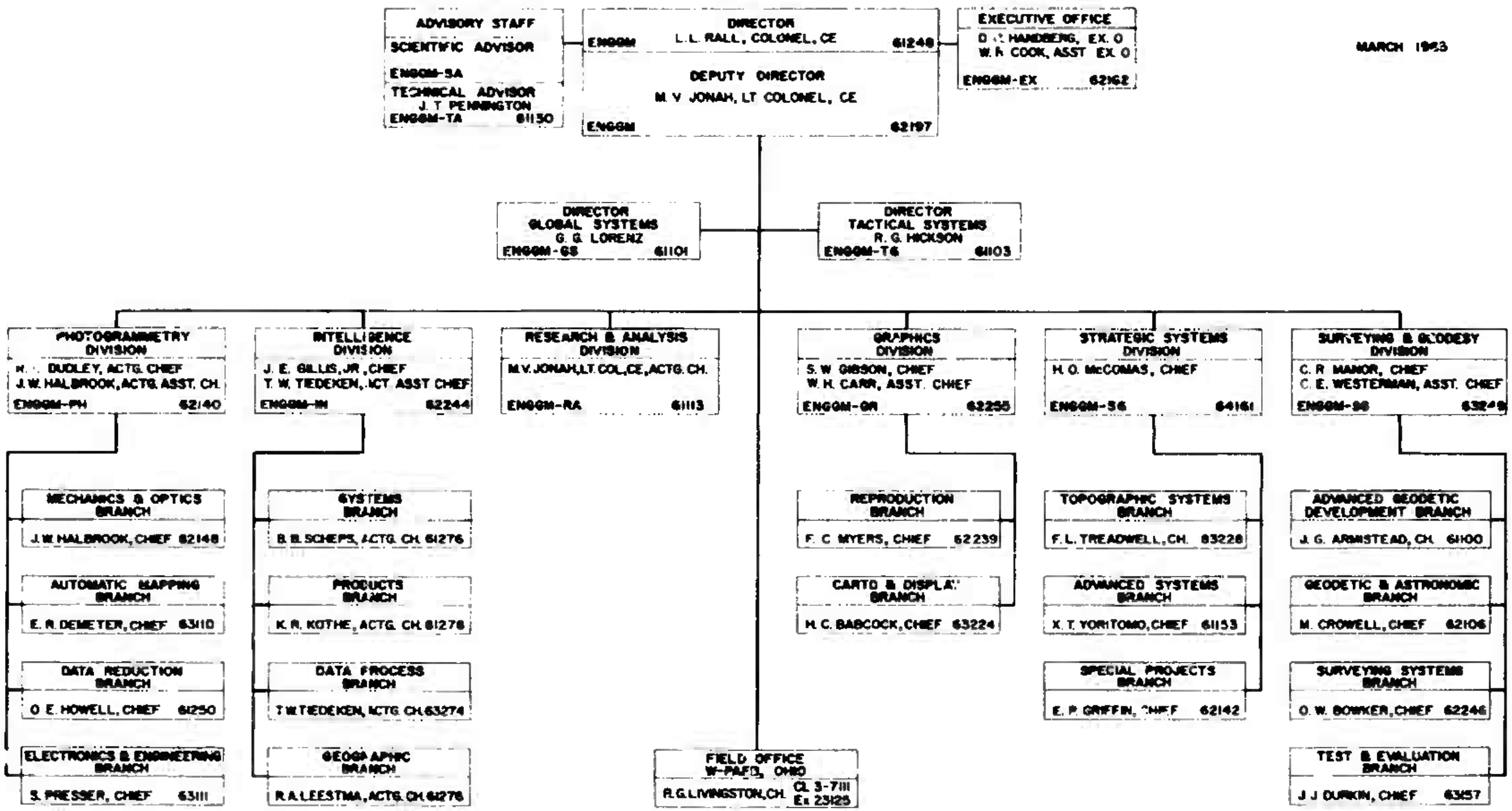
SCIENTIFIC ADVISOR
TECHNICAL ADVISOR
DIRECTOR GLOBAL SYSTEM
DIRECTOR TACTICAL SYSTEM
USAF LIAISON OFFICE
USASRDL LIAISON OFFICE
RESEARCH AND ANALYSIS DIVISION
INTELLIGENCE DIVISION
STRATEGIC SYSTEMS DIVISION
PHOTOGRAMMETRY DIVISION
SURVEYING AND GEODESY DIVISION
GRAPHICS DIVISION

U. S. ARMY ENGINEER GEODESY INTELLIGENCE AND MAPPING RESEARCH AND DEVELOPMENT AGENCY

FORT BELVOIR, VIRGINIA

MARCH 1963

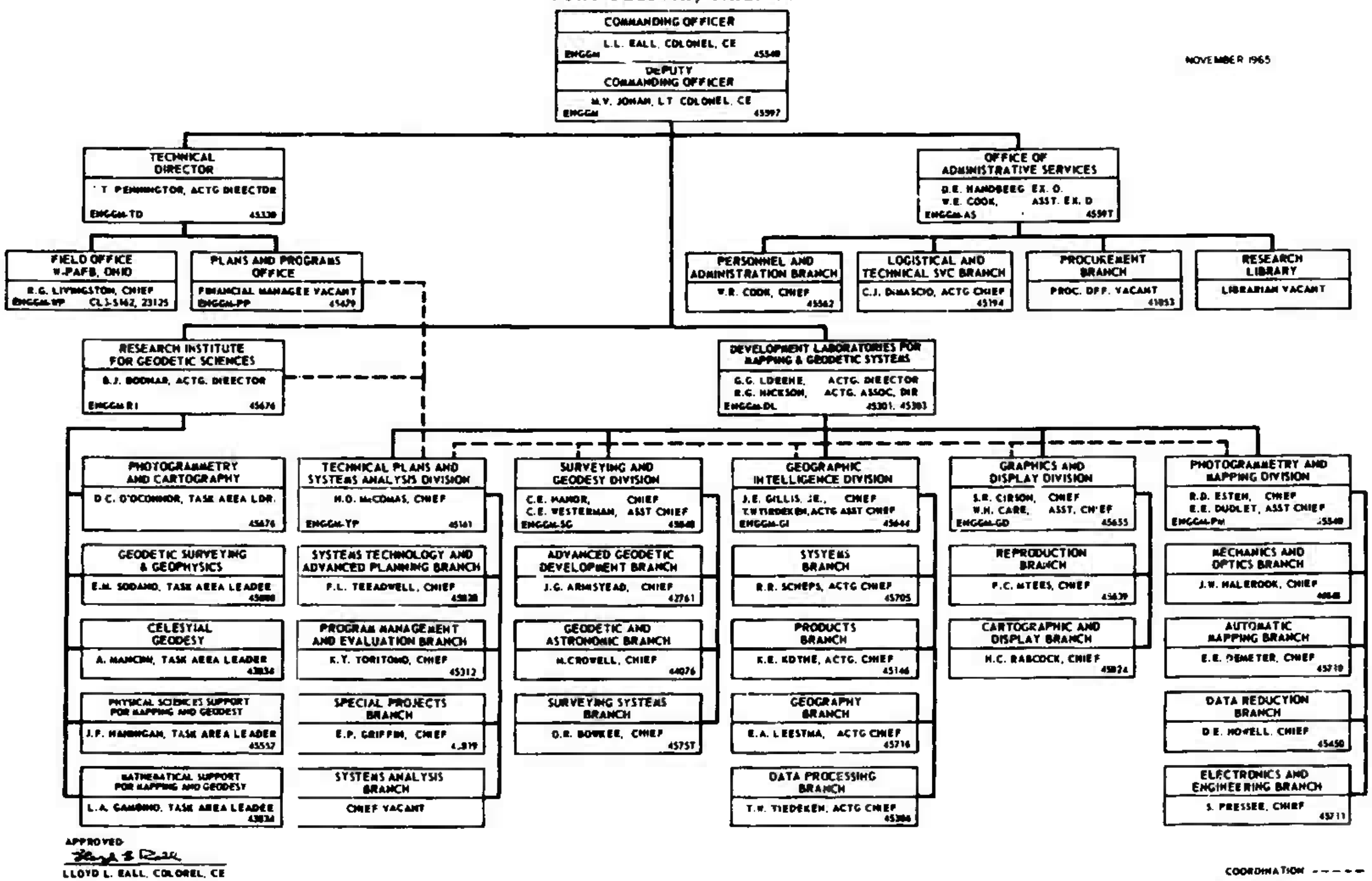


APPROVED:

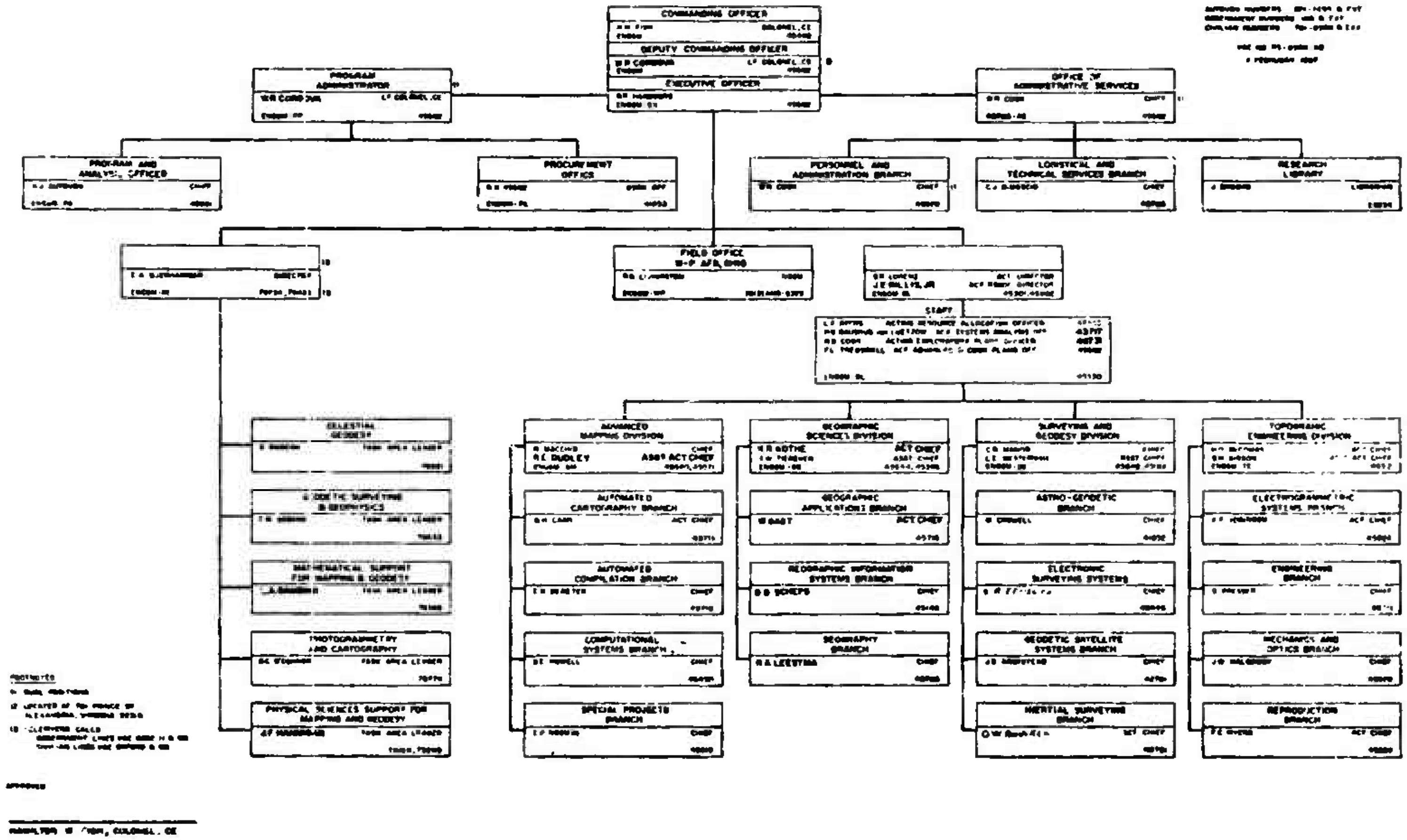
Lloyd L. Rall

LLOYD L. RALL, COLONEL, CE

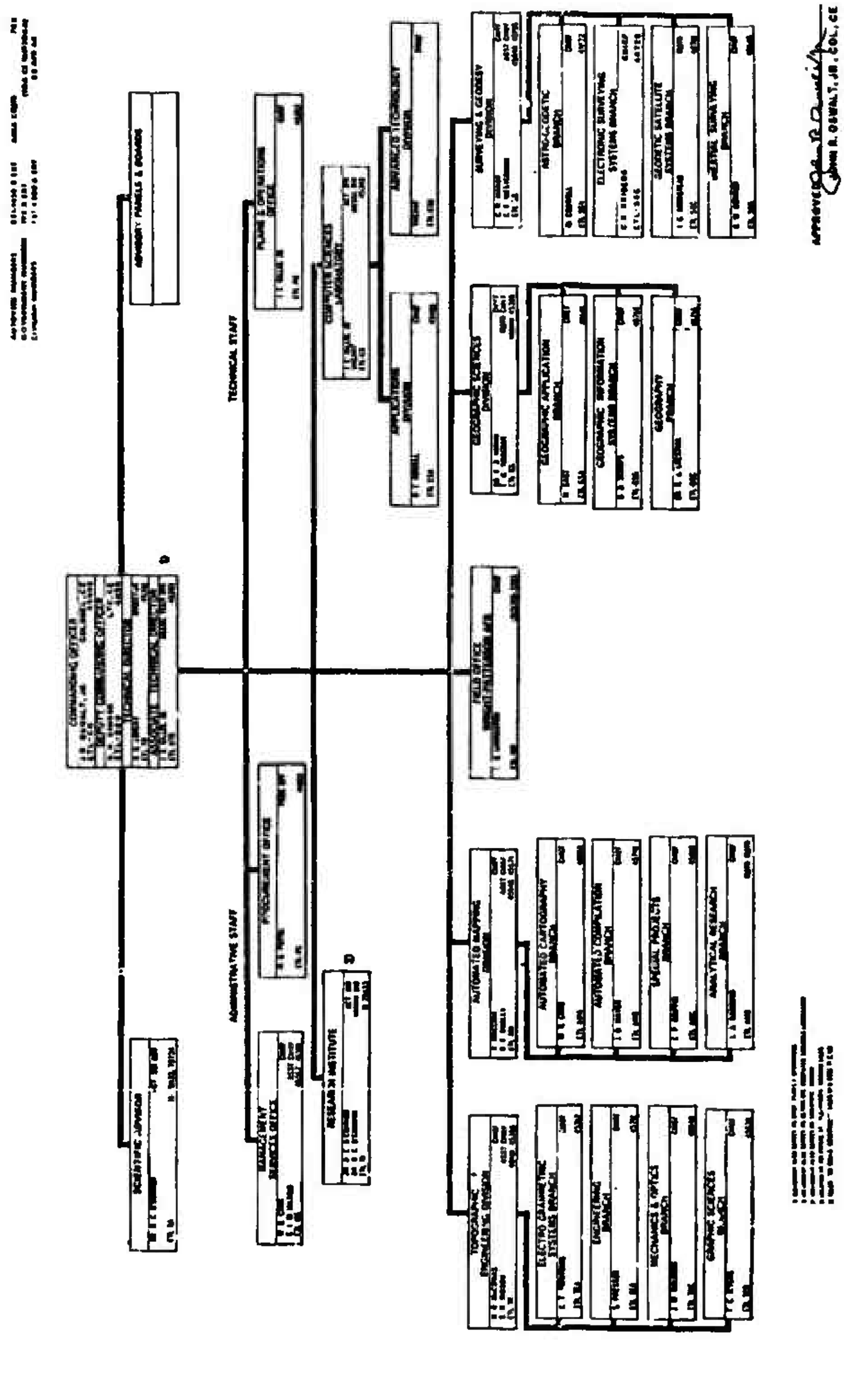
U.S. ARMY ENGINEER GEODESY INTELLIGENCE AND MAPPING RESEARCH AND DEVELOPMENT AGENCY
FORT BELVOIR, VIRGINIA



U. S. ARMY ENGINEER GEODESY INTELLIGENCE AND MAPPING RESEARCH AND DEVELDPMENT AGENCY
FORT BELVOIR, VIRGINIA



U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES, FT. BELVOIR, VIRGINIA 22060



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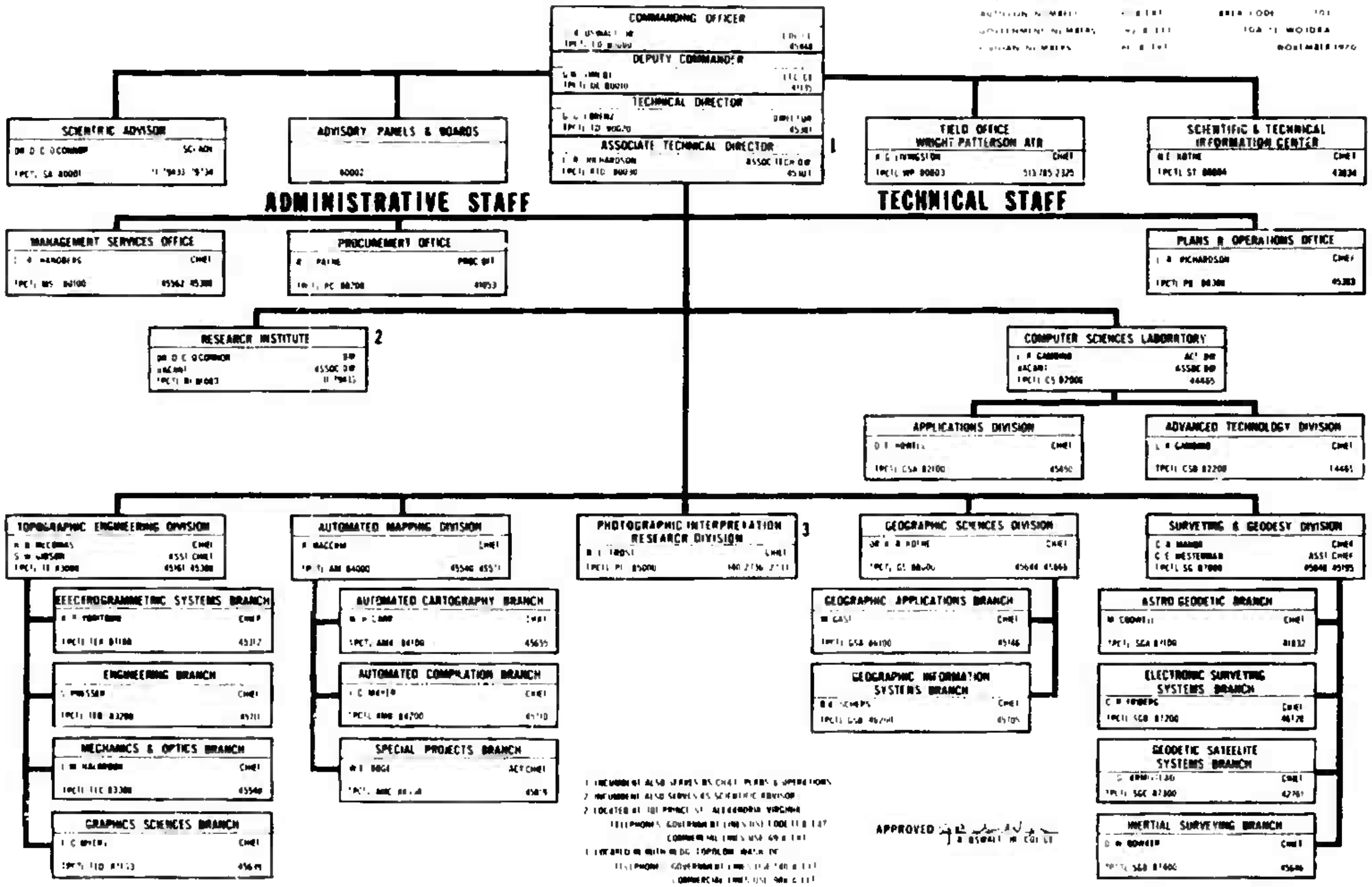

APPENDIX B

PERSONNEL RESPONSIBLE FOR TOPOGRAPHIC RESEARCH AND DEVELOPMENT THROUGH WORLD WAR II

Captain R. R. Arnold, Secretary, Engineer Board

Major James W. Bagley, CO, Engineer Detachment

Joseph H. Bakewell, Mapping Branch, Engineer Board

Major Harold E. Beaty, Engineer Detachment

Fred H. Bloom, Mapping Branch, Engineer Board

Michael H. Bruno, Chief, Research Section, Army Map Service

John B. Canada, Mapping Branch, Engineer Board

CWO J. C. Cosby, Mapping Branch, Engineer Board

Major William C. Cude, Director, Technical Division V, Engineer Board

Major Frederick J. Dau, Chief, Mapping Branch, Engineer Board

Charles P. Deibel, Lithographer, Army Map Service

Captain George P. DeRosa, Photo and Lithographic Branch, Engineer Board

Lewis A. Dickerson, Chief, Photogrammetric Division, Army Map Service

Douglas Dingwall, Aerial Photographic Branch. Engineer Board

F. W. C. French, Topographic Branch, Office, Chief of Engineers

Joseph H. Fuller, Mapping Branch, Engineer Board

Henry H. Furman, Mapping Branch, Engineer Board

George C. Garraway, Consulting Engineer, Engineer Board

Charles M. Gilmore, Mapping Branch, Engineer Board

Barnard R. Halpern, Engineer, Mapping Branch, Engineer Board

Colonel Bruce C. Hill, CO, Engineer Detachment

Captain Jack Kronenburg, Army Map Service

John E. Lewis, Jr., Engineer, Desert Test Branch, Engineer Board

Harry A. Lieberman, Mapping Branch, Engineer Board

Major William S. Little, Mapping Branch, Engineer Boaro

Colonel Herbert P. Loper, Chief, Military Intelligence Division, Office, Chief of Engineers

Major Gilbert G. Lorenz, Chief, Photogrammetric Branch, Engineer Board

Charles R. Manor, Engineer, Ground Control Branch, Engineer Board

Colonel A. G. Matthews, Chief, Military Intelligence Division, Office, Chief of Engineers

John J. O'Kane, Mapping Branch, Engineer Board

John T. Pennington, Engineer, Photogrammetric Branch, Engineer Board

William H. Pistel, Superintendent, Reproduction Division, Army Map Service

John R. Richardson, Chief, Topographic Branch, Office, Chief of Engineers

Robert E. Rossell, Chief, Photo and Lithographic Branch, Engineer Board

Irwin K. Roth, Topographic Branch, Office, Chief of Engineers

Captain Louis J. Rumaggi, CO, Engineer Detachment

Colonel Karl B. Schilling, Engineer Board

Major Eldon D. Sewell, Chief, Aerial Photographic Branch, Engineer Board

Captain Emil Shute, Mapping Branch, Engineer Board

James G. Strobridge, Chief, Reproduction Division, Army Map Service

Captain Benjamin B. Talley, CO, Engineer Detachment

LT Juan R. de Torres, Jr., Aerial Photographic Branch, Engineer Board

W. B. Van Wagner, Topographic Branch, Office, Chief of Engineers

Joseph Walsh, Photomechanical Branch, Army Map Service

Colonel R. T. Ward, President, Engineer Board

Captain Montgomery L. Webster, Mapping Branch, Engineer Board

APPENDIX C

PERSONNEL OF TECHNICAL DEPARTMENT V, ENGINEER BOARD, AND TOPOGRAPHIC ENGINEERING DEPARTMENT, ENGINEER RESEARCH AND DEVELOPMENT LABORATORIES RESPONSIBLE FOR DEVELOPMENT FROM WORLD WAR II TO 1960

Leonard W. Andrukonis, Surveying and Geodesy Branch

Abraham Anson, Project Engineer, Map Compilation Branch

John G. Armistead, Project Engineer, Electronic Survey Section, Surveying Branch

Sidney Augarten, Project Engineer, Map Reproduction Branch

Lawrence F. Ayers, Project Engineer, Topographic Systems Branch

Homer C. Babcock, Project Engineer, Topographic Systems Branch

Clyde E. Berndsen, Project Engineer, Aerial Photographic Branch

Sidney H. Birdseye, Consultant, Surveying Branch

Bela J. Bodner, Chief, Research Section, Topographic Systems Branch

Oscar W. Bowker, Chief, Survey Test Section; Chief, Air and Ground Techniques Section

Berthold Brenner, Map Reproduction Branch

William H. Carr, Project Engineer, Cartography Section, Map Compilation Branch

Lt. Alfred R. Castorina, Map Reproduction Branch

Eugene J. Chillemi, Project Engineer, Photo and Litho Branch

CWO W. C. Chipka, Chief, Survey Studies Section

CWO J. Chomjack, Chief, Experimental Photo Section, Photogrammetric Branch

William J. Chudej, Project Engineer, Surveying Branch

W. R. Clarke, Chief, Reproduction Service Section; Chief, Technical Photo Branch; Chief, Technical Photo Laboratory

Barnard A. Claveloux, Chief, Data Reduction Section, Map Compilation Branch

John G. Collins, General Engineer, Map Compilation Branch

John G. Colwell, Map Reproduction Branch

CWO J. C. Cosby, Surveying Branch

Clifford J. Crandall, Project Engineer, Map Compilation Branch

Melvin Crowell, Project Engineer, Surveying and Geodesy Branch

William C. Cude, Director, Technical Division V, Engineer Board; Chief, Topographic Engineering Department, Engineer Research and Development Laboratories

WO David W. Davia, Map Compilation Branch

W. W. Davis, Chief, Reproduction Studies Section, Map Reproduction Branch

Quinty C. DeAngelis, Project Engineer, Map Compilation Branch

E. R. DeMeter, Chief, Analytical and Automatic Mapping Section, Map Compilation Branch

George P. DeRosa, Chief, Mobile Reproduction Section, Photo-Litho Branch

WO AM DeYoe, Chief, Special Studies Section, Ground Control Branch

Paul W. Dorst, Consultant, Map Reproduction Branch

Robert E. Dudley, Chief, Photomapping Section; Chief, Applications Engineering Section, Map Compilation Branch

John J. Durkin, Chief, Applications Engineering Section, Surveying and Geodesy Branch

Randall D. Esten, Chief, Map Compilation Techniques Section; Chief, Analytical and Automatic Mapping Section; Assistant Chief, Map Compilation Branch

Arthur H. Faulds, Project Engineer, Photogrammetry Branch

Theodore L. Fick, Project Engineer, Map Compilation Branch

Carl R. Friberg, Jr., Project Engineer, Surveying and Geodesy Branch

Seymour J. Friedman, Chief, Photogrammetry Section, Map Compilation Branch

Ernest E. Gallegos, Project Engineer, Survey Equipment Section, Surveying Branch

Francisco F. Garcia, Project Engineer, Map Compilation Branch

Von G. Geckeler, Jr., Chief, Equipment Analysis Section, Map Reproduction Branch; Chief, Applications Engineering Section, Topographic Systems Branch

Stephen W. Gibson, Chief, Photo-Litho Section, Chief, Research Section, Map Reproduction Section, Topographic Systems Branch

James E. Gillis, Jr., Research Section, Topographic Systems Branch

Eugene P. Griffin, Project Engineer, Photogrammetry Section, Map Compilation Branch

J. Wiley Halbrook, Chief, Stereoscopic Equipment Section; Chief, Photomapping Section

Jacob M. Halsey, Project Engineer, Photogrammetry Section, Map Compilation Branch

Donald R. Handberg, Administrative Assistant, Topographic Engineering Department

CWO George S. Hanlen, Map Compilation Branch

Jean A. Hardesty, Mathematician, Map Compilation Branch

Rolland R. Hardy, Project Engineer, Surveying Branch

Thomas J. Hepler, Equipment Specialist, Map Reproduction Branch

Robbins G. Hickson, Assistant Chief, Topographic Engineering Department

Alan R. Holland, Project Engineer, Surveying and Geodesy Branch

Hobbs H. Horak, Project Engineer, Map Reproduction Branch

Merle L. Horton, Project Engineer, Map Reproduction Branch

Dale F. Howell, Chief, Data Reduction Section, Map Compilation Branch

George M. Illemszky, Photographer, Photogrammetry Section

Ivan R. Jarrett, Project Engineer, Photogrammetry Section

Quentin S. Johnson, Chief, Cartography Section, Map Reproduction Branch

CWO P. H. Kasten, Map Reproduction Branch

Ronald L. Keener, Map Reproduction Branch

J. H. Kelly, Jr., Chief, Reproduction Studies Section, Photo-Litho Branch

Ray A. Kelsey, Project Engineer, Photogrammetric Branch

Clarence W. Kitchens, Assistant Chief, Survey Test Section

William Klein, Project Engineer, Map Compilation Branch

Wilhelm Krieger, Consultant, Map Reproduction Branch

Earl R. L'Abbe, Map Reproduction Branch

R.P.E. Laschober, Map Compilation Branch

Charles C. Lane, Photogrammetric Branch

Robert G. Livingston, Chief, Aerial Photographic Branch

Major Willian J. Locke, Chief, Photomapping Section, Photogrammetric Branch

Gilbert G. Lorenz, Chief, Photogrammetric Branch, Technical Division V; Chief, Map Compilation Branch, Topographic Engineering Department

Robert P. Macchia, Project Engineer, Map Compilation Techniques Section, Map Compilation Branch

Silas A. Maddox, Project Engineer, Development Section, Map Reproduction Branch

William C. Mahoney, Project Engineer, Photogrammetric Branch

Armando Mancini, Mathematician Surveying and Geodesy Branch

Charles R. Manor, Chief, Surveying and Field Astronomy Section, Ground Control Branch; Chief, Surveying and Field Astronomy Section, Surveying Branch

Ralph Marzocco, Chemist, Map Reproduction Branch

Robert L. Matos, Project Engineer, Map Compilation Branch

Major Walter R. Mazetis, Military Assistant, Topographic Engineering Department

John D. Mayer, Project Engineer, Topographic Systems Branch

Howard O. McComas, Chief, Cartography Section, Map Compilation Branch; Chief, Special Mapping Techniques Section, Map Compilation Branch; Chief, Systems Analysis Section, Topographic Systems Branch

Frank A. McFarland, Chief, Mobile Reproduction Section, Map Reproduction Branch; Chief, Reproduction Equipment Section, Map Reproduction Branch; Assistant Chief, Topographic Systems Branch

Ransford P. McGregor, Chief, Survey Studies Section, Surveying Branch; Chief, Planning and Evaluation Group, Topographic Engineering Department

G. B. I. Miller, Chief, Reproduction Studies Section, Map Reproduction Branch

Frederick C. Myers, Project Engineer, Research Section, Map Reproduction Branch

Steven R. Nagy, Project Engineer, Surveying and Geodesy Branch

CWO A. Nelson, Chief, Special Studies Section, Photo-Litho Branch

John T. Pennington, Chief, Special Studies Section, Photogrammetric Branch; Chief, Photogrammetric Studies Section, Photogrammetric Branch; Chief, Map Reproduction Branch, Topographic Engineering Department; Chief, Topographic Systems Branch, Topographic Engineering Department

Sidney Presser, Project Engineer, Map Compilation Branch

LTC H. E. Rice, Military Assistant, Topographic Engineering Department

Robert M. Rawls, Project Engineer, Surveying Branch

Maorits Roos, Project Engineer, Map Compilation Branch

George H. Rosenfield, Map Compilation Techniques Section, Map Compilation Branch

Robert E. Rossell, Chief, Photo-Litho Branch, Technical Department V; Chief, Map Reprodoction Branch, Topographic Engineering Department

Joseph P. Rostron, Project Engineer, Map Compilation Branch

Walter P. Scales, Chief, Geodetic and Astronomic Section, Surveying and Geodesy Branch

Bernard B. Scheps, Cartographer, Topographic Systems Branch

George P. Schreiber, General Engineer, Topographic Engineering Department

Gonther Schwarz, Photographer, Map Compilation Branch

Eldon D. Sewell, Chief, Aerial Photographic Branch, Topographic Engineering Department

Melvin C. Shetler, Chief, Groond Control Branch, Technical Department V; Chief, Surveying Branch, Topographic Engineering Department; Chief, Sorveying and Geodesy Branch, Topographic Engineering Department

Guy H. Stockwell, Lithographic Technician, Map Reprodoction Branch

Donald Snyder, Map Reprodoction Branch

Theodore W. Tiedeken, Project Engineer, Map Compilation Branch

Frank L. Treadwell, Project Engineer, Map Compilation Techniqocs Section, Map Compilation Branch; Liaison Engineer, Signal Research and Development Laboratories

George P. Tyson, Chief, Reproduction Service Section, Photo-Litho Branch

M/Sgt Alvin H. Vollmer, Map Compilation Branch

Alfred J. Watson, Chief, Photomapping Section, Map Compilation Branch

C. E. Westerman, Chief, Electronic Sorvey Section, Sorveying and Geodesy Branch

George E. Whiting, Project Engineer, Aerial Photographic Branch; Project Engineer, Map Compilation Techniques Section, Map Compilation Branch

Archer M. Wilson, Chief, Shoran Section, Photogrammetric Branch

Harry W. Woo, Project Engineer, Photogrammetric Branch

Marshall S. Wright, Jr., Project Engineer, Photogrammetric Branch

Kent T. Yoritomo, Project Engineer, Map Compilation Branch

APPENDIX D

TECHNICAL REPORTS ON DEVELOPMENT

ENGINEER BOARD REPORTS

EB REPORT 501, *Test of Stadia Traverse for Field Artillery*, by Thomas North, 8 July 1937

EB REPORT 505, *Overlay Paper*, by R. R. Arnold, 6 August 1937

EB REPORT 506, *Portable Stereoscope*, by R. R. Arnold, 7 August 1937

EB REPORT 509, *Photographic Equipment for Engineer Troops*, by R. R. Arnold, 24 September 1937

EB REPORT 510, *Map Reproduction Equipment*, by R. R. Arnold, 6 October 1937

EB REPORT 521, *Aerial Photographs for Preparation of Military Maps*, by R. R. Arnold, 10 February 1938

EB REPORT 531, *Organization and Equipment of Topographic Battalions*, by R. R. Arnold, 18 April 1938

EB REPORT 544, *Report on Test of Fire Control Data Sheet, Fort Sill, Oklahoma, 1937*, by Thomas North, 10 August 1938

EB REPORT 565, *Map Reproduction Equipment*, by R. R. Arnold, 17 February 1939

EB REPORT 576, *Aerial Photography Reading*, by R. R. Arnold, 16 June 1939

EB REPORT 583, *Corps Mapping Unit*, by R. R. Arnold, 27 September 1939

EB REPORT 589, *General Doctrine for Mapping in Enemy Territory*, by R. R. Arnold, 17 January 1940

EB REPORT 591, *Map Reproduction Equipment*, by R. R. Arnold, 28 June 1940

EB REPORT 599, *General Doctrine for Mapping in Enemy Territory*, by R. C. Crawford, 11 December 1940

EB REPORT 663, *Improvement of the Battle Map*, by Gilbert G. Lorenz, 10 July 1942

EB REPORT 664, *Military Mapping From Tri-Metrogon Aerial Photography*, by Lewis A. Dickerson, 15 June 1943

EB REPORT 668, *Wide Angle Mapping Equipment,* by Gilbert G. Lorenz, 10 April 1942

EB REPORT 693, *Vectographs,* by Lewis A. Dickerson, 10 July 1942

EB REPORT 717, *Special Military Level,* by Joseph H. Bakewell, 29 August 1942

EB REPORT 719, *Surverkrop Pocket Transit,* by W. S. Little, 26 October 1942

EB REPORT 722, *One Second Theodolite,* by Joseph H. Bakewell, 19 September 1942

EB REPORT 723, *Surveying Altimeters,* by Joseph H. Bakewell, 4 December 1942

EB REPORT 727, *Rapid Production of Photographic Prints,* by William C. Cude, 20 November 1942

EB REPORT 791, *Astrolabes (Equiangulators),* by William S. Little, 5 February 1944

EB REPORT 812, *Japanese Magnetic Compasses,* by J. C. Cosby, 11 May 1944

EB REPORT 824, *Italian Semiprecise Level,* by J. C. Cosby, 5 June 1944

EB REPORT 830, *Military Mapping From Tri-Metorgon Aerial Photography Using Rectified Photographs,* by John T. Pennington, 17 June 1944

EB REPORT 836, *Japanese Drafting Equipment,* by J. C. Cosby, 8 July 1944

EB REPORT 840, *German Map Reading Light,* by J. C. Cosby, 17 July 1944

EB REPORT 841, *German One-Second Theodolites,* by J. C. Cosby, 17 July 1944

EB REPORT 843, *Mosaics for Field Artillery,* by Emil Shutc, 21 July 1944

EB REPORT 851, *Miscellaneous Japanese Surveying Instruments,* by J. C. Cosby, 8 August 1944

EB REPORT 852, *The Iconoscope,* by John T. Pennington, 15 August 1944

EB REPORT 870, *Field Tests of Short-Base Triangulation and Subtense-Bars,* by H. A. Lieberman, 22 September 1944

EB REPORT 871, *Portable Perspective Sketcher (Hehr-O-Graph),* by John T. Pennington, 22 September 1944

EB REPORT 872, *Improvement of Multiplex Reduction Printers,* by John T. Pennington, 26 September 1944

EB REPORT 889, *Japanese Compass-Clinometer,* by J. C. Cosby, 9 November 1944

EB REPORT 920, *Investigation of Timepiece for Astro-Fixes,* by J. C. Cosby, 24 March 1945

EB REPORT 932, *Investigation and Tests of Zenith Cameras,* submitted by Giles L. Evans,* 14 May 1945

EB REPORT 973, *Vertical Control for Aeronautical Charting and Mapping,* submitted by Giles L. Evans,* 27 February 1946

EB REPORT 987, *Application of Shoran to Mapping,* by Archer M. Wilson, 29 August 1946

ENGINEER RESEARCH AND DEVELOPMENT LABORATORY REPORTS

ERDL REPORT 1001, *Cold Weather Tests of Topographic Equipment,* by Walter C. Chipka and William J. Locke, 1 August 1947

ERDL REPORT 1012, *An Investigation of Control Point Photography in Shoran Mapping,* by Archer M. Wilson and Arthur H. Faulds, 1 September 1947

ERDL REPORT 1014, *Comparison of the Stereotopograph and the K. E. K. Plotter,* by William J. Locke, 15 September 1947

ERDL REPORT 1020, *Two Step Rectification of High Oblique Aerial Photographs,* by Frank A. McFarland, 17 December 1947

ERDL REPORT 1044, *Helicopter Survey Methods for Mapping,* by Ransford P. McGregor, 15 March 1948

ERDL REPORT 1047, *Modification and Test of the Stereoplanigraph,* by John T. Pennington and J. W. Halbrook, 26 April 1948

ERDL REPORT 1055, *Tentative Operating Instructions for Shoran Photogrammetric Mapping,* by Archer M. Wilson, 6 August 1948

ERDL REPORT 1059, *Duplication of Aerial Negatives,* by S. J. Friedman, 26 August 1948

ERDL REPORT 1063, *Cold Weather Tests of Surveying Equipment,* by Clarence W. Kitchens, 17 September 1948

ERDL REPORT 1081, *Utilization of Shoran for Mapping,* by Archer M. Wilson, 5 November 1948

ERDL REPORT 1084, *Evaluation of German Klein Autographs,* by Frank A. McFarland, 5 November 1948

*For a period of approximately 1 year in 1945 and 1946, all Engineer Board Technical Reports were submitted by the Director of the technical division in which they were prepared. Giles L. Evans was Director of Technical Division I. Authors of these reports are unknown.

ERDL REPORT 1100, *Theodolite, 10-Second,* by Charles R. Manor, 28 January 1949

ERDL REPORT 1103, *Development of Projector, Multiplex, Oblique, Wide Angle,* by Harry W. Woo, 14 January 1949

ERDL REPORT 1106, *A Derivation of Simplified Formulas for Computing Shoran Range and Path Height,* by Arthur H. Faulds, 1 February 1949

ERDL REPORT 1107, *Contouring Inaccessible Areas Having Limited Vertical Control,* by Archer M. Wilson, 4 March 1949

ERDL REPORT 1109, *Light-Sensitive Diazotype Papers for Tropical Use,* by Wilhelm Krieger, 8 April 1949

ERDL REPORT 1110, *Auxiliary Equipment for Shoran Photogrammetric Mapping,* by Arthur H. Faulds, 8 April 1949

ERDL REPORT 1112, *Tribrach Universal,* by John J. Durkin, 8 April 1949

ERDL REPORT 1120, *Astronomical Attachment, Azimuth Determination, Reflecting, for Transit or Theodolite,* by Charles R. Manor, 13 May 1949

ERDL REPORT 1122, *Sensitizers for the Production, by the Diazo-Ammonia Process, of Nonphotographic, Blue-Line Drafting Boards,* by J. H. Kelly, 6 May 1949

ERDL REPORT 1124, *Development of Autofocus Rectifying Projection Printer,* by Harry W. Woo, 13 May 1949

ERDL REPORT 1125, *Development of Portable Autofocus Reflecting Projector,* by Frank A. McFarland, 13 May 1949

ERDL REPORT 1129, *Investigation of the Ryker PL-3 Plotter,* by James W. Halbrook, 17 June 1949

ERDL REPORT 1133, *An Investigation of Slotted Templet Methods in Shoran Mapping,* by Charles C. Lane, 8 July 1949

ERDL REPORT 1144. *Tripod, Universal,* by John J. Durkin, 30 September 1949

ERDL REPORT 1145, *Tower, Triangulation, Lightweight,* by John J. Durkin, 30 September 1949

ERDL REPORT 1146, *Computer, Survey, Electric, IBM,* by Clarence W. Kitchens, 30 September 1949

ERDL REPORT 1151, *Development and Testing of Heater-Ventilator, Gasoline Burning, for Reproduction Van,* by George P. DeRosa, 8 December 1949

ERDL REPORT 1152, *Altimeter, Surveying, 15,000 Foot, 5-Foot Divisions,* by Oscar W. Bowker, 6 December 1949

ERDL REPORT 1153, *Compass, Sun, Universal, O to 90 Degrees, North and South Latitudes, with Case,* by Ransford P. McGregor, 6 January 1950

ERDL REPORT 1154, *Compass Lensatic,* by C. Edward Westerman, 6 January 1950

ERDL REPORT 1158, *Development of Height Finder, Oblique, Topographic,* by Randall D. Esten, 28 February 1950

ERDL REPORT 1161, *Printer, Photographic, Horizontal Projection, Rectifying, Tilts Under 70° for 9½-inch Aerial Roll Film,* by Frank A. McFarland, 13 March 1950

ERDL REPORT 1168, *Shoran Photogrammetric Mapping Instructions,* by Archer M. Wilson, 15 May 1950

ERDL REPORT 1172, *Development of Lithographic Offset Press, 22 by 29-inch Sheet Size,* by Thomas J. Hepler, 16 June 1950

ERDL REPORT 1173, *Compilation and Evaluation of Topographic Maps and Controlled Mosaics Prepared From 40,000 Foot Altitude Photography of Fort Sill, Oklahoma,* by John T. Pennington. 28 June 1950

ERDL REPORT 1174, *Engineering Test of Experimental Ammonia Process Printer-Developer,* by John H. Kelley, 6 July 1950

ERDL REPORT 1176, *Field Resolution Tests with the Metrogon Lens,* by Eldon E. Sewell and Robert G. Livingston, 4 August 1950

ERDL REPORT 1181, *Cold Weather Tests of the Sun Compass and Lensatic Compass,* by Ranford P. McGregor, 22 September 1950

ERDL REPORT 1182, *Test of Cartographic Bases,* by R. D. Esten, 4 October 1950

ERDL REPORT 1183, *Compass, Wrist,* by C. Edward Westerman, 5 October 1950

ERDL REPORT 1185, *Photoangulator,* by Howard O. McComas, 18 October 1950

ERDL REPORT 1187, *Body, Van, Expansible, T-1,* by Frank A. McFarland, 24 October 1950

ERDL REPORT 1189, *Reliefograph Machine,* by W. W. Davis, 19 December 1950

ERDL REPORT 1191, *Investigation and Evaluation of the Kelsh Plotter,* by Seymour J. Friedman, 10 April 1951

ERDL REPORT 1192, *Terrain Model Making Equipment, Portable, Set No. 1, General Purpose,* by W. W. Davis, 20 January 1951

ERDL REPORT 1192, *Radio Time Comparator*, by Oscar W. Bowker and J. C. Cosby, 19 March 1951

ERDL REPORT 1194, *Development and Testing of Camera, Copying, Mobile, Process 24 by 30 Inch*, by Merle L. Horton and Stephen W. Gibson, 6 April 1951

ERDL REPORT 1195-L, *Target Grid*, by Alfred J. Watson, 27 April 1951

ERDL REPORT 1197, *Theodolite, 1-Minute*, by Charles R. Manor, 1 May 1951

ERDL REPORT 1199, *Tripod, Ranging Poles*, by J. C. Cosby, 11 May 1951

ERDL REPORT 1202, *Tripod, Universal*, by John J. Durkin, 21 May 1951

ERDL REPORT 1204-L, *Development of Projector, Multiplex, Oblique, Wide Angle*, by Harry W. Woo, 31 May 1951

ERDL REPORT 1205, *Investigation of Photographic Requirements for Mapping From High Altitude Photography*, by Marshall S. Wright, 4 June 1951

ERDL REPORT 1207, *Theodolite, 01-Second*, by J. C. Cosby, 13 June 1951

ERDL REPORT 1208, *Slotted Templet Set with Radial Stainless Steel Arms and Plywood Chest*, by Howard O. McComas, 25 July 1951

ERDL REPORT 1209, *Mapping From Radar Presentations*, by Randall D. Esten, 24 July 1951

ERDL REPORT 1212, *Development of Portable Autofocus Reflecting Projector*, by Harry W. Woo, 24 August 1951

ERDL REPORT 1218, *Mathematical Aids to Shoran Operational Planning*, by Randall D. Esten, 28 September 1951

ERDL REPORT 1219, *Tangential Distortion in the Metrogon Lens*, by Robert G. Livingston, 5 November 1951

ERDL REPORT 1223, *Cold Weather Testing of 1-Second Direction Theodolite, 10-Second Direction Theodolite, Universal Tripod, and Astronomical Attachment*, by Charles R. Manor, 5 January 1952

ERDL REPORT 1227, *Development of 22 x 29-Inch Spirit Duplicator*, by George P. DeRosa, 28 April 1952

ERDL REPORT 1229-L, *Development of 24 x 30-Inch Mobile Process Copying Camera*, by Stephen W. Gibson, 6 May 1952

ERDL REPORT 1230, *Helicopter Survey Methods for Mapping, Flare-Signal Triangulation Test*, by Robert M. Rawls and J. C. Cosby, 19 May 1952

ERDL REPORT 1233, *Multiplex Equipment, Motorized,* by Quentin S. Johnson, 29 May 1952

ERDL REPORT 1235, *Comparative Tests and Evaluation of Multiplex, Kelsh Plotter, Stereoplanigraph, Wild Autograph Model A-5, and Wild Stereoplotter Model A-6,* by J. W. Halbrook and John T. Pennington, 30 May 1952

ERDL REPORT 1238-L, *Ranging Pole Tripod,* by John J. Durkin, 10 June 1952

ERDL REPORT 1239, *Tower, Triangulation, Lightweight,* by John J. Durkin, 26 June 1952

ERDL REPORT 1241, *Fairchild Lithotype Composing Machine,* by Donald Snyder, 7 July 1952

ERDL REPORT 1242, *Effects of Earth Curvature and Atmospheric Refraction Upon Measurements Made in Stereoscopic Models of High Altitude Photography,* by Ray A. Kelsey, 9 July 1952

ERDL REPORT 1243, *Instruments, Plotting, Stereoscopic, Multiplex, Set No. 7, Short Frame,* by Marshall S. Wright, Jr., 15 July 1952

ERDL REPORT 1246, *Electronic Flash Light Source for n Process Copying Camera,* Earl R. L'Abbe, 28 July 1952

ERDL REPORT 1247, *Development of Lithographic Offset Press, Mobile, 22½- by 30-Inch Maximum Sheet Size,* by Guy N. Stockwell, 1 August 1952

ERDL REPORT 1250, *Lensatic Compass,* by C. Edward Westerman, 2 September 1952

ERDL REPORT 1252, *Precise Astronomic Equipment Set,* by J. C. Cosby, 19 August 1952

ERDL REPORT 1253, *Preparation of Intermediates for the Quantity Reproduction of Aerial Contact Prints by the Ammonia Process,* by Berthold Brenner, 12 September 1952

ERDL REPORT 1258-L, *Reproduction Equipment, Topographic, Motorized Map Layout Section, Set No. 2,* by Hobbs H. Horak, 17 October 1952

ERDL REPORT 1259, *Fotosetter (FS-4) Photolettering Machine,* by Donald Snyder, 28 October 1952

ERDL REPORT 1264, *Expansible Van Body (Engineer),* by Marshall S. Wright, Jr., 14 November 1952

ERDL REPORT 1266, *Compass, Wrist,* by C. Edward Westerman, 28 November 1952

ERDL REPORT 1267, *Engineering Tests of the Cartographic Van (of the Army Topographic Battalion and the Corps Topographic Company) and the Supply Van (of the Army Topographic Battalion)*, by William Klein, 1 December 1952

ERDL REPORT 1269, *Engineering Test of Mirror Stereoscope*, by J. W. Halbrook, 3 December 1952

ERDL REPORT 1274, *Oblique Sketchmaster*, by Howard O. McComas, 24 December 1952

ERDL REPORT 1288, *Cold Weather Testing of 10-Second Direction Theodolite, 1-Minute Direction Theodolite, 1-Second Direction Theodolite (Foreign Model), Astronomical Attachment, and Winterization Kit*, by William J. Chudej, 29 April 1953

ERDL REPORT 1289, *Hot Weather Testing of 10-Second Direction Theodolite with Universal Tribrach and Universal Tripod, Astronomical Attachment, Universal Sun Compass, Lensatic Compass, and Wrist Compass*, by Oscar W. Bowker, 29 April 1953

ERDL REPORT 1290, *Engineering Test of Opaque Cartographic Bases*, by Robert E. Dudley, 30 April 1953

ERDL REPORT 1292, *Engineering Tests of Two Printer-Developers, Ammonia Processor, 24 Inch*, by Sidney Augarten, 12 May 1953

ERDL REPORT 1294, *Radar Relief Displacement and Radar Parallax*, by Randall D. Esten, 12 May 1953

ERDL REPORT 1305, *Cartographic Drafting Methods and Equipment*, by William C. Mahoney, 7 July 1953

ERDL REPORT 1307, *Development, Service Tests, and Production Model Tests of Autofocusing Rectifier*, by Ray A. Kelsey, 7 July 1953

ERDL REPORT 1311, *Test and Evaluation of the Kelsh Plotter, Model 5000, Manufactured by the Instruments Corporation*, by Seymour J. Friedman, 21 August 1953

ERDL REPORT 1329, *Desk Model Fotosetter Photo-Lettering Machine*, by Donald Snyder, 6 November 1953

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APPENDIX E

ROSTER OF TECHNICAL PERSONNEL OF THE GEODESY INTELLIGENCE AND MAPPING RESEARCH AND DEVELOPMENT AGENCY AND ITS SUCCESSOR THE ENGINEER TOPOGRAPHIC LABORATORIES RESPONSIBLE FOR RESEARCH AND DEVELOPMENT SINCE 1960

Abraham Anson, Project Engineer, Photogrammetry Division; General Engineer, Systems Branch, Geographic Intelligence Division; Acting Chief, Geographic Information Systems Branch, Geographic Sciences Division

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Russel G. Arnold, Chemist, Cartographic and Display Branch, Graphics Division

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Homer C. Babcock, Chief, Cartographic and Display Branch, Graphics Division

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James S. Bizzell, Electronic Engineer, Surveying Systems Branch, Surveying and Geodesy Division

E. A. Bjerhammer, Director, Research Institute

Art T. Blackburn, Physicist, Data Reduction Branch, Photogrammetry and Mapping Division

Bela J. Bodnar, Assistant Chief, Research and Analysis Division; Acting Director, Research Institute

Walter E. Boge, General Engineer, Special Projects Branch; Acting Chief, Special Projects Branch, Automated Mapping Division

Andrew J. Bondurant, General Engineer, Test and Evaluation Branch, Photogrammetry Division; General Engineer, Electronics and Engineering Branch, Photogrammetry and Mapping Division

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Alfred R. Castorina, Cartographer, Carto and Display Branch, Graphics Division

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Joseph P. Goodwald, Equipment Specialist, Cartography and Display Branch, Graphics Division

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